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# THE SCIENTIFIC MONTHLY

*EDITED BY J. McKEEN CATTELL*

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# THE SCIENTIFIC MONTHLY

AUGUST, 1924

## THE SCIENTIFIC WORK WHICH OUR GOVERNMENT IS CARRYING ON AND ITS INFLUENCE UPON THE NATION[1]

By Dr. GEORGE K. BURGESS

DIRECTOR, U. S. BUREAU OF STANDARDS

In visualizing the picture of the scientific work of the federal government in its setting of service to the public, you will appreciate the necessity of our viewing the picture as a whole from a distance. It will be possible to indicate only the main theme and point out briefly some of the salient characteristics. This picture is heroic in size, grandiose in composition, harmoniously designed, vigorously drawn, possesses a wealth of color, and is executed with marvelous skill and painstaking care. As we approach it we shall see first in the foreground an indication of some of the semi-governmental activities, and then the broad, brightly lighted canvas on which is set forth, each in its proper relation to the others, the many-hued scientific activities of the government in which appear the portraits of not a few great men, and as we examine the dimmer background we may catch glimpses of less well-defined traits which will be better understood with the passage of time.

April 28 last marks a memorable date in the progress of science in the United States, for on that day was dedicated in Washington the building of the National Academy of Sciences and National Research Council, the two scientific organizations recognized by the federal government; the former founded by Congress in 1863 and the latter in 1917 by the President of the United States through the instrumentality of the academy. At this ceremony, the government was represented by the President who began his address by stating:

> If there be one thing in which America is preeminent, it is a disposition to follow the truth. It is this sentiment which characterizes the voyage of

[1] Commencement address, Case School of Applied Science, May 29, 1924.

Columbus. It was the moving impulse of those who were the leaders in the early settlement of our country, and has been followed in the great decisions of the nation through its history. Sometimes this has been represented by political action, sometimes by scientific achievements. On this occasion, the emphasis is on the side of science.

One of the duties of the academy is to act, when called upon, as scientific adviser to the government, and one of the important matters it has thus considered was a study of our forestry policy in 1896 resulting in constructive legislation; and it has again, at the request of the chief forester, decided at this April meeting to assist in formulating a plan for the conservation, restoration and utilization of our forest reserves, a problem of the utmost urgency to our national welfare, and one whose economic significance many of you as engineers will soon appreciate as relating to the supply and use of a basic material of your profession.

The Research Council was formed for the purpose of organizing and bringing to the aid of the government in war time the services of the scientific men of the country in the solution of the many intricate problems involving applications of science to warfare. The council was continued after the war for the purpose of initiating, correlating and stimulating research throughout the country. With its scientific divisions centered at Washington, and its division of engineering with headquarters in New York City, together with its many affiliations scattered over the land, the council is guiding a great part of our research work.

We are living in a world of associative effort in overcoming the difficult tasks that confront us in science and engineering, and you as young engineers will soon learn that few of the problems with which you will have to deal can be solved without consulting others from seemingly unrelated fields. To-day, the engineer must be highly trained in some particular line of activity in which he may hope, with application and opportunity, to become in time an authority, but he constantly finds himself as he progresses upward in his profession calling for help from the physicist, the chemist, the biologist, the physician and many others in the solution of his engineering problems. This mutual dependence is well illustrated by the investigation recently completed by the National Research Council on the marine borer—an animal that destroys our seaboard structures—requiring the coordinated efforts of the engineer, the chemist and the biologist, both within and without the government service.

Another instance of such cooperative effort, involving advice as to the expenditure not merely of millions but of billions of dollars, is the committee of highway research instituted for the purpose of developing the best types of road construction and materials for the

country, and composed of engineers, technologists and scientists, representing the federal and state governments, as well as engineering societies and other interested national bodies. But perhaps the most striking illustration of the dependence of the engineer upon another profession was given in the construction of the greatest engineering work of modern times, the Panama Canal, which could hardly have been built, except at the cost of a terrible toll in lives, unless the medical men had first eliminated yellow fever from the isthmus.

Nearly a hundred years ago a British subject, James Smithson, left about a half million dollars to found at Washington under government supervision "an establishment for the increase and diffusion of knowledge among men." The Smithsonian Institution was established by Congress in 1846 "to assist men of science in making original researches, to publish them in a series of volumes, and to give a copy of them to every first-class library on the face of the earth." The Smithsonian now administers a great library, museums, zoological park and gallery of art, and carries out many explorations and other scientific activities, mainly related to American ethnology, anthropology and archeology.

A notable series of eminent men have headed this institution: Joseph Henry, famed for his electrical researches and his work in meteorology out of which came the weather bureau; S. F. Baird, founder of the fish commission, now the bureau of fisheries; Langley, the father of aeronautics, who also established the astro-physical laboratory; and Walcott, who is unexcelled in his chosen field of geology.

The federal government has long realized the need of scientific aid and associative effort in the solution of many problems of public interest, and by generous grants to the various executive departments has nurtured what the President has called "the opportunity for inspiring the people of America to insistence upon having the truth, and nothing but the truth, regarding everything that touches our life as a nation."

The oldest of the strictly governmental scientific services—which is also an engineering branch—is the Coast and Geodetic Survey established early in the last century under Hassler, a Swiss who brought with him our standards of length, weights and measures, in which establishment for many years, or until 1901, was invested the custody and development of our weights and measures. Out of this unit has sprung the greatest of our national laboratories, the Bureau of Standards, with its many scientific, technical and engineering activities, founded and developed for twenty-two years under the direction of S. W. Stratton.

You will recall how that giant among men, Leonardo, great in poetry, letters, painting, sculpture, architecture, science and technology, military and civil engineering, always began a painting by a most rigorous scientific study of the geometry and mechanics of his subject, supplemented by semi-finished studies. Similarly, viewed as a constructive work of art by the nation, it was fitting that there were first laid down the geometry and mechanics of the picture in the establishment of our weights, measures and geodetic base lines, and the precise astronomical work of the Naval Observatory and National Almanac Office, followed by a series of sketches as illustrated in the incomplete but manifold activities of the early Smithsonian Institution. From these foundations has sprung the scientific work of the government, as we see it to-day, as yet an unfinished picture, as again were so many of Leonardo's.

As agriculture is the most vital and extensive of our industries, on which all else may be said to depend for existence, so the development of scientific research in agricultural problems by the government has been cultivated more extensively than any other branch. Our picture thus becomes a landscape with appropriately grouped trees, plants and living creatures, clouds and soil, in which we recognize symbolized some of the fifteen great bureaus of the Department of Agriculture, such as forestry, plant industry, entomology, biological survey, soils, weather, public roads and animal industry. Here again, we are following the canvas of Leonardo who so skilfully blended his subject in a landscape in which appeared many manifestations of nature.

Our picture shows a continuous struggle against the inroads of disease in plants and animals, and for the maintenance of food supply and food standards; prevision against damage by the atmospheric elements, floods, forest fires and factory dust explosions; for improvement of roads, the preservation of bird life and the elimination of insect pests. The establishment of the Bureau of Fisheries gave the government an instrument for the scientific control and development of another of our great food-producing industries.

The government has not neglected in its scientific work questions relating to man himself, and consequently we have the public health service with its hygienic laboratory devoted to research in such matters as epidemics, social and occupational diseases.

Our mineral resources have in recent years become a matter of increasing concern to the federal government, their discovery, survey, development and conservation, as well as their application in industry and the arts. To meet these needs of the public there were established such units as the Geological Survey and the Bureau of Mines, which are the great governmental agencies for aiding the

mining industries of the country. There are in this field many fascinating problems, some of them of tremendous import to our industrial fabric. For example, our steel industry, by far the largest in the world, producing some 45,000,000 in a total of 71,000,000 tons yearly, is dependent on an adequate supply of manganese, most of which is imported. If our supply were cut off, what would we do? If we could not obtain enough manganese, our whole industrial organization would suffer unless a substitute method of manufacturing steel economically could be devised, or other materials developed. Here is a national problem of the first magnitude which may become acute, and perhaps some graduate of Case School may help to solve. There are other basic raw materials essential to modern industry not produced by our country, such as tin and rubber, the lack of which has stimulated governmental research to fill the gaps.

We do not ordinarily consider the military departments of War and Navy as productive scientific units of the government; but we may be sure that Leonardo, if he were to-day to compose a painting symbolizing the scientific work of the government, would give them a prominent place in his picture. It is but necessary to remind you of the strides made by these departments in radio communication during the war and since; the developments in aeronautical science, including aerodynamics and engine design; in explosives, which find their greatest application in civilian uses; and the rebirth of the science of acoustics, with its numerous applications in signalling. For many years the ordnance bureaus of the War and Navy departments have done more than any other agency in improving and maintaining the quality of special steels, out of which the metal materials of our automotive industry have grown. To the navy we owe our most marked advance in knowledge and application of steam, producing increasingly higher speed boats with wonderfully concentrated power units such as the modern turbine. Here it is possible to experiment on a large and comparative scale, as no private party can afford, on such matters as electric drive, internal combustion engines, and oil burners. Viewed in this light, the military departments, in addition to their prime function as national insurance and defense, become a very real asset in peace times for the advancement of science as related to industry.

One of the most recently established scientific branches of the government is the National Advisory Committee for Aeronautics, an interdepartmental board with civilian members from outside the service, which is charged with fundamental investigations relating to aeronautics. This committee maintains a laboratory at Langley Field near Norfolk, Virginia, and also supports scientific research at the Bureau of Standards and elsewhere.

I have left till the last the Bureau of Standards, realizing that if I had commenced with it, there would have been little room in our picture for the other scientific activities of the government. This bureau, with a population of some 800, of whom over 500 comprise the scientific and technical staff, is located on a commanding site some three miles from the center of Washington. It is splendidly housed in eleven permanent and several temporary buildings and possesses an unparalleled equipment for scientific research, the testing of many kinds of instruments and the investigation of numerous materials of engineering and technological processes.

The bureau, in addition to carrying out elaborate experimental work in the establishment and maintenance of standards relating to measurements of length, mass, capacity, time, electricity, optics, heat and other branches of physics and chemistry, is concerned also with the exact determination of many fundamental constants such as melting points, densities, specific heats, electrical and thermal conductivities, refractive indices, standard wave lengths, coefficients of expansion and of electrical resistance and a multitude of others of importance to science and industry. Investigations of a fundamental nature are also undertaken, such as problems in atomic physics, X-rays, radioactivity, the properties of steam and ammonia, the corrosion of metals, the ratio of the electrical units to each other, the constant of gravitation, the laws of aerodynamics, the theories of structures and the constitution of cements. Many of these basic problems are of a kind requiring very elaborate experimental arrangements and group cooperation over long periods of time, and are therefore particularly adapted to solution in a government laboratory. Instruments of all kinds from thermometers and chemical glassware to saccharimeters and wave meters are tested and the staff of the bureau have devised many new ones, with aeronautical instruments in the lead, and improved others. New materials are studied to determine their properties and availability for use in many fields of industry.

In addition to its purely scientific work, the bureau is also actively engaged in many technological lines such as metallurgy, ceramics, including optical glass, which the bureau manufactures, leather and rubber, textiles, paper and the materials of engineering. These investigations are planned largely with the help of advisory committees representing industry. A great deal of effort is spent in improving standards of quality of materials of technological and engineering importance; determining standards of performance of machines and devices such as automotive engines and elevator interlocks; and developing standards of practice, as illustrated by safety and service codes for industry and public utilities. Much of this

work leads to the formulation of purchase and operating specifications for use not only by the government but also by states and municipalities as well as in commercial transactions and industrial operations.

The bureau may also be said to be the consulting, research and testing laboratory in physics, chemistry, technology and many branches of engineering for the United States government. With the public, as represented mainly by manufacturers, engineering bodies, state and municipal authorities, the bureau has widespread, close and cordial relations. Inquiries for information requiring written replies and requests for services average over 300 a day, so that in addition to their laboratory work the staff of the bureau carries on a heavy, highly specialized correspondence.

The scientific output of the Bureau of Standards, as of the other government departments, is made available in publications distributed principally by the superintendent of documents.

And now we have completed as comprehensive a view as the time permits of this picture of the scientific work of the government. I trust you have found the picture a true one, an inspiring one. Its truth some of you, perhaps all of you, may have occasion to verify. One can not live in its atmosphere without becoming enthused with its uplifting qualities. The more often one contemplates and studies its details, the more one becomes impressed with its high ideal representing accomplishment, sincerity, beauty and truth. It is not a picture set apart in an inaccessible gallery, but is a very part, perhaps the most highly developed, responsive and vital part, of the life of the nation.

# ASTRONOMICAL OBSERVATORIES IN THE UNITED STATES PRIOR TO 1848

By Professor W. C. RUFUS

UNIVERSITY OF MICHIGAN

An early American astronomical observatory may be defined as a tube with an eye at one end and a star at the other. Such observatories played an important part during the days of discovery, exploration and settlement.

The successful outcome of the voyage of Columbus depended upon observations of the stars, as attested by a leaf from his journal.[1] "Monday, 17th of September [1492]. The pilots observed the north point and found that the needles turned a full point to the west of north. So the mariners were alarmed and dejected." Columbus succeeded in allaying the fears of the pilots and the sailors by an ingenious, though specious, explanation based upon the motion of the heavenly bodies. Thus he was able to hold his crew, as well as his course, by an appeal to the stars.

Scientific "discouverers," equipped with mathematical and astronomical instruments, accompanied the voyages of some of the exploring and colonizing parties. Sir Thomas Hariot, the first English man of science to visit the New World, joined the second expedition to Virginia sent out by Sir Walter Raleigh, in 1585. His equipment and its effect upon the natives are given in his own words:[2]

> Most things they saw with us, as mathematical instruments, sea compasses, the virtue of the loadstone in drawing iron, a perspective glass whereby was shewed many strange sights, burning glasses, wildfire works, guns, books, writing and reading, spring clocks that seem to go of themselves, and many other things that we had, were so strange unto them and so far exceeded their capacities to comprehend the reason and means how they should be made and done, that they thought they were rather the works of gods than of men, or at the leastwise they had been given and taught us by the gods.

Hariot did not describe his "perspective glass." As he also mentions burning glasses we conclude that he possessed lenses. About twenty-five years later he was contemporary with Galileo in the telescopic observation of celestial objects.

Stars were observed during inland trips to direct the course

[1] The Journal of Christopher Columbus (The Hakluyt Society), 24, 1893.

[2] Narrative of the First English Plantation of Virginia (1588), Quaritch Reproduction, 39, 1893.

through the wilderness of the New World. The following letter[3] from James Alexander to Cadwallader Colden illustrates the practice.

Swartwoot's at Mackackemack
June 27th, 1719.

D Doctor

our Luck was so good in a passage That on Tuesday after I Left you we got to Esopus where we Staid till Thursday dureing which time we observed Lucida Aquile in which observation

| | | | |
|---|---|---|---|
| fiducial Edge cutt | 34° | 37′ | |
| Plummett Cut | ° | 52′ | |
| Z Distance | 33° | 45′ | |
| Hevelin's Declin: W[t] allowance for 58½ years | 8° | 10′ | 21″ |
| | 41 | 55 | 21 |

on Thursday we Set out from Esopus towards Mackackemack where yesterday we arrived all Safe and Sound and this morning we observed Lucida Aquile in which plummet cut 95° 49′ 30″ fid Edge 62° 35′ 30″ which makes us guess we are 15½′ to the Southward of our Latitude.

Astronomical observations for their own sake, for the love of science, also began in America at an early date. One of the earliest colonial observers to receive recognition abroad was Thomas Brattle, of Boston. "Baily,[4] in his supplement to the account of Flamsteed, states, that 'Mr. Thomas Brattle, of Boston in New England, is the annonymous person alluded to by Newton, in his Principia, as having made such good observations of the comet of 1680.'" Several of his observations are preserved in the Transactions of the Royal Society of London. On June 12, 1694, he observed an eclipse of the sun at Cambridge, four miles from Boston, New England. The eclipse observations[5] were preceded and followed by taking altitudes of the sun "to rectify the watch." The time of the beginning of the eclipse and the attainment of digits 1, 3, 4, 5, 6, 8, 9, 9½, 10 and 10½ (evidently on the basis of 12) were recorded, also the time of the corresponding decrease and of the end of the eclipse. Final results are given to the nearest minute of time as follows:

| | | | |
|---|---|---|---|
| Began at | 9h | 14′ | Mane |
| Ended | 0 | 38 | P. M. |
| Lasting in all | 3 | 24 | |

In the calculation the latitude of Boston was allowed to be 42° 25′.

[3] Cadwallader Colden Papers. The New York Historical Society collection, 1917, Vol. I, 99, 1918.

[4] Quincy, "History of Harvard University," Vol. I, 412, 1860.

[5] Benjamin Motte, "Philosophical Transactions Abridged," Vol. I, 264, 1721.

Brattle's observations of lunar eclipses in 1700, 1703 and 1704 are also published. An item of the first is interesting: "$6^h$ 42¼′. The shadow near an inch from Palus Maraeotis, Mons Horminius and Mons Hercules." His equipment is briefly mentioned. "My clock was set by my Ring-Dial about 9 a Clock in the Morning, as exactly as I could judge, and the observation was made with my 4½ Foot Telescope, with all four Glasses in it." Greater time accuracy was attempted at the eclipse of December 22, 1703. In addition to the use of the Ring-Dial, he observed both the rising and the setting of the sun and found that his clock went "very steadily and regularly." Then he adds: "But for the greater Certainty and Satisfaction, I took the Altitudes of the following stars with the Brass Quadrant with Telescope Sights out of my chamber window, the lowness whereof would not permit me to take them, when they were at all higher elevated." The three stars observed were, "In dextro humero Orionis, Procyon and Regulus." The range of the time corrections was 26 seconds. Observations on the lunar eclipse of December 11, 1704, compared with London gave a difference of longitude of $4^h$ $43^m$.

Another colonial observer, whose work deserves more than passing mention, was Thomas Robie, who observed at Salem and at Cambridge. His earliest note preserved in the Philosophical Transactions refers to an earthquake. Astronomical observations followed.[6] On February 13, 1716–1717, he observed an immersion of the first satellite of Jupiter, at $10^h$ 48′ 17″; and on February 8, he observed an emersion at $8^h$ 7′ 30″; according to which the difference of longitude between Harvard College and Upminster is $4^h$ $45^m$. His observation of the lunar eclipse of March 15, 1717, with "a 24-foot telescope," compared with the observations of Cassini and De la Hire, of Paris, made Cambridge, New England, $4^h$ $55^m$ $50^s$ west of Paris.[7]

Accurate latitude and longitude determination of other important centers was undertaken for the benefit of the geographers and surveyors. Contemporary with the work of Brattle and Robie in Boston, Douglas mentions that of Sir William Keith in Philadelphia and Cadwallader Colden in New York.

Preeminent among the early observations for astronomical value, rather than for geographical position, may be given those of Thomas Robie on the sun and Mercury. An unaddressed letter from Robie found among the Cadwallader Colden papers gives a full account of two observations.[8]

[6] Philosophical Transactions of the Royal Society of London (Abridged), Vol. VII, 530, 1809.

[7] Cadwallader Colden Papers, Vol. I, 166, 1918.

[8] Cadwallader Colden Papers, Vol. I, 159, 1918.

From Thomas Robie

(Unaddressed)

(Gov. William Burnet ?)

May it Please your Excellency

Sir

Hearing, by my very good Friend mr Jacob Wendal of Boston, of your Excellency's very great Knowledge in, & Affection to, Astronomy, & also of your great pleasure in receiving any Astronomical Observations, I venture at this time to cummunicate to you Two Observations wch I have made within about a Year past. The first is ye Observation of ye Sun's Eclipse in Nov. 1722, wch I made at Cambridge N. E. when I lived at ye College there, & it is thus, viz.

Nov. 27. 07h 27′ am: I Saw ye Sun rise eclipsed, on its Supreme Vertex to ye South abt 4 Digits Tho some Persons on ye Top of ye New College Saw it 2 or 3 mins before. The true rising of ye Sun this morning was 7h 30′ Hence ye Refraction is abt 6 min. & So much I have often observed it here in ye Winter Time. From this time I could observe no more by reason of Clouds. But at—

8.30′. — or there about ye Sun appeared again, & was I judg'd only by bear Occular Observation Eclipsed 6. Digts

8.55. 15″ — The Sun was Eclipsed 4¾ Dig. nearest. & then ye Diameter of ye Sun was to ye Moon's as 1000 to 972 as well as I could Observe.

9.00. 15 When 4½ Dig. nearest wn hid, ye ☉ Diameter was to ☽ as 1000 to 975.

9.19. 45 A little Spot in ye Sun, on its Eastern Limb emerged. The Spot was of this form ◦V◦.

9.25. 45 I Saw ye Moon thro' a 24 feet Telescope go off ye Sun, & so ye Eclipse ended.

9.25. 45 Mr. Danforth in a darkned Room just by me saw ye Shadow go off ye Paper abt 30 degrs from ye Lower Vertex to ye East, & So did mr Appleton, ye Minister of Camb. in a darkned room a little distant from College, See ye Shadow leave ye Paper at

9.25. 20

And as I am informed ye Center of ye Shaddow, past over Cape Cod. 2d The Second Observation is of mercury's being Seen in ye Sun, Oct. 29. last & it is thus, viz. Salem Oct. 29. 1723. Abt 11 in ye morning I saw ☿ thro' a 9 feet Telescope, advanc'd on ye ☉ disk 6 or 8 min' of ye Sun's diamr It appear'd like a little black spot: abt 12.½ It was advanc'd near to ye Line Perpendicular to ye Ecliptic, & abt one I saw it & it had then Crost ye Axis, & abt ½ past 2. I saw it abt as far from ye Western Limb, as it was from ye Eastern in ye Morning wn I first saw it. By Several observations wch I made very carefully & distinctly, I judged yt there is an atmosphere round ☿ for round ye black spot wch was ☿ there was a dim light like a Halo, or wt ye Vulgar call a buss round ye ☽ when there are thin clouds. I took particular Notice of this because such Transits give ye Best opportunity to observe whether there is an

atmosphere round these Inferiour Plannets or no; & if I a'nt mistaken ♀ has one, & larger in proportion than ye ☉. As for ye Eclipses ye next Year, 1724. Those yt will be vis. here I shall observe & if your Excellency shall do me ye honour of desiring my Obs. I shall readily obey You. There will be a Large Solar Eclipse in May next, Central & total in ye South west of England, as doubtless yr Excellency well knows, & so I only add yt it will be here abt 7 or 8 dig. as I remember I made it when I calculated it some years agoe. I have long wish'd for good Observations to be made at New York, but dispared, till I heard of yr Excellency's disposition, & now I hope ye Longitude between here & there will be established, wch will be a public Service.

I beg your Excellency's pardon for my Present Writing, & assure You I could not refuse doing it, from a desire I have of advancing my self in Astronomy, & hope your Excellency will be pleased to help me here in by your Communications, & yt You will be pleased always to account me,

Yours Excellency's

Most humble & Obedient Servant

THOMAS ROBIE.

Salem N. E. Nov. 9. 1723.

Professor John Winthrop, of Harvard, observed a transit of Mercury, April 27, 1740, with a 24-foot aerial telescope. His expedition to Newfoundland in 1761 to observe the transit of Venus was the first scientific expedition in this country provided by public expense. In 1769 he observed the transit of Venus at Cambridge.

Mason and Dixon arrived from England in 1763 to settle a boundary dispute between Pennsylvania and Maryland. Their first work in this country was to establish a surveying station and to determine its position with great care and accuracy. The building erected for this work, just south of the city of Philadelphia, was called Mason and Dixon's observatory. Extensive astronomical observations were made in 1763 and 1764, and the reduction of the data has been styled the first astronomical computation in America.

The greatest astronomical activity in America during the colonial period centered about the transit of Venus in 1769. The American Philosophical Society appointed three committees to make observations at Philadelphia, Norriton and Cape Henlopen. Temporary observatories were erected and instruments were obtained chiefly from London. The observations were successful and are given a prominent place in the first volume of the Transactions of the American Philosophical Society, and received favorable comment in England.

The work of David Rittenhouse deserves special consideration in this connection. His instrument shop on the Norriton farm was the center of astronomical activity before the time of the transit of Venus. Here he made the clocks and the instruments which he used at the time of the observations. He determined the position of the station and carried out the preliminary computations necessary for

the success of the undertaking. The accuracy of the observations at Norriton exceeded those of Dr. Thomas Ewing at Philadelphia, Owen Biddle at Cape Henlopen and those of Professor Winthrop previously mentioned at Harvard. Indeed, it seems that the Norriton results equalled the best obtained by Europeans. The calculations for Greenwich and Norriton, corrected for the spheroidal form of the earth, gave for the external contact a solar parallax of 8.″805. The present adopted value is 8.″80. Among the other observers were the English astronomers at Hudson's Bay, Madras and the South Sea Island, Otaheite, the French in California, the Russian at different points of Siberia and Russia, the Danish at the North Cape and the Swedish in Finland. Here we find American astronomical observations taking their place by the side of those made by Europeans, and we have not yet found the first real American astronomical observatory, a building erected and equipped with instruments designed for permanent observational use.

Following the success of the American observations of the transit of Venus an attempt was made to found an observatory in this country. Goode[9] says: "Had not the Revolution taken place, it would undoubtedly have resulted in the establishment of a well-equipped observatory in this country under the auspices of the home government." Dr. Ewing approached Lord North, the prime minister of England, and Mr. Maskelyne, the astronomer royal; and his project to establish an observatory in Philadelphia met with favor. The approach of the war made further cooperation impossible, as indicated in a letter from Maskelyne to Ewing in August, 1775:

> In the present unhappy situation of American affairs, I have not the least idea that anything can be done toward erecting an Observatory at Philadelphia, and therefore can not think it proper for me to take a part in any memorial you may think proper to lay before my Lord North at present. I do not mean, however, to discourage you from presenting a memorial from yourself. Were an observatory to be erected in that city, I do not know any person there more capable of taking care of it than yourself.

We believe there was a more capable man, David Rittenhouse. Before the transit of Venus had called forth special astronomical activity in the colonies, Rittenhouse, in his tool house on the Norriton farm, studied mathematics and astronomy, made clocks, and other mathematical and astronomical instruments, and began the accumulation of the equipment which played an important part on that occasion. This appears to be the reason for the selection of his site for a transit station. According to Goode,[10] "his observa-

[9] Annual Report of the Smithsonian Institution, 310, 1897.

[10] Report of the Smithsonian Institution, 412, 1897.

tory, built at Norriton in preparation of the transit of Venus in 1769, seems to have been the first in America." Soon after this event, Rittenhouse moved to Philadelphia, and his fellow-citizens, through the American Philosophical Society, petitioned the Philadelphia legislature, March 6, 1775, for an appropriation to enable them to erect an observatory and to grant Rittenhouse a salary as the "public astronomical observer." But the call to arms prevented the execution of the plan. Although Rittenhouse responded to public duty during the war, his astronomical zeal did not abate. On November 2, 1776, he observed a transit of Mercury; on January 9, 1777, an eclipse of the sun; on June 24, 1778, one week after the British evacuation of Philadelphia, he observed another solar eclipse.

The erection of his private observatory in Philadelphia, without aid from England or the Pennsylvania legislature, marks the establishment of the first astronomical observatory in this country deserving the name and receiving recognition. Goode says,[11] "When Washington became President . . . there were no scientific foundations within this repubic save the American Academy in Boston, and in the American Philosophical Society, Bartram's Botanic Garden, the private observatory of Rittenhouse, and Peal's Natural History Museum, Philadelphia." We do not know the exact date of the erection of his observatory. It was built on his "observatory lot" before he constructed his residence in Philadelphia in 1786. The observatory was "a small but pretty convenient octagonal building of brick in the garden adjacent to his dwelling" at the corner of Arch and (Delaware) Seventh streets. To adjust his transit instrument he invented the collimating telescope and he independently discovered the use of spider threads in the ocular. At the death of Rittenhouse, in 1796, the only observatory in the United States closed its doors.

Evidence of the existence of a short-lived observatory contemporary with Rittenhouse is given by his communication to the American Philosophical Society[12] containing observations made in 1789 at the University of William and Mary by the Reverend Dr. James Madison. "As the observatory in which the transit instrument had been formerly placed, was not, at this time, rebuilt, I was not enabled to attend to the going of the time-keeper, by means of such observations as I wished to have made." His equipment for observations included a sextant and an achromatic telescope magnifying about 60 times. He observed a lunar eclipse,

[11] "The origin of the national scientific and educational institutions of the United States." American Historical Association Papers, Vol. IV, Part 2, 310, 1890.

[12] Transactions of the American Philosophical Society, Vol. III, 150, 1793.

November 2, 1789, and a transit of Mercury, November 5, of the same year. Dr. Madison also includes observations of the transit of Mercury made by Professor Andrews with a reflector by Short with a magnifying power of 90. Lalande did not seem to know of the existence of this observatory, as he mentions only Rittenhouse's in the United States at that time.

Little astronomical work was done by the succeeding generation. The statesmen of the new republic, however, encouraged the development of science. Washington in his first message to Congress said: "Nor am I less persuaded that you will agree with me in opinion that there is nothing more deserving your patronage than the promotion of science and literature." Jefferson, who possessed marked scientific tendencies, contributed to the Proceedings of the American Philosophical Society and served a term as its president. These men, however, like Franklin and other master minds, called to more pressing political problems, gave their best efforts to the patriotic task of establishing the new republic on a secure foundation. Washington looked forward to the founding of a great national university. Barlow's "Prospectus of a national institution," in 1806, included plans for a national observatory. Hassler, in 1807, advocated the erection of two observatories at a great distance apart for the service of the Coast and Geodetic Survey. Instruments were obtained in 1816, one 6-foot Dolland achromatic telescope, two similar 5-foot instruments, two transits, two astronomical clocks, six chronometers, theodolites, compasses, reflecting circles, thermometers, etc. But Bowditch[13] laments as late as 1825: "It is to be regretted that no better use is made of them than to lock them up, after some have been spoiled, like articles of curiosity in a museum." In the meantime Congress was besieged by earnest advocates of the need of a national observatory. James Monroe, in 1812, when he was secretary of state, urged that deliberate body in vain. William Lambert, of Virginia, memorialized Congress frequently from 1810 to 1822; on the last occasion he presented an elaborate report on the need of an observatory. John Quincy Adams, in 1825, in his annual message to Congress, said: "It is with no feeling of pride, as an American, that the remark may be made that, on the comparatively small territorial surface of Europe there are existing upward of one hundred and thirty of these lighthouses of the skies; while throughout the whole American hemisphere there is not one." His proposition was ridiculed, and the expression, "lighthouse in the sky," became a common jest.

Airy, afterward the astronomer royal of England, in a report on the progress of astronomy, presented in 1832 to the British

[13] *North American Review*, April, 1825.

Association for the Advancement of Science, included a complete list of the observatories of the world and added: "I am not aware that there is any public observatory in America, though there are some able observers." In 1840, just eight years before the American Association for the Advancement of Science held its first meeting, a Boston correspondent of the London *Athenaeum*, commenting on the lack of observatories in the United States, said:[14] "True, nothing has yet been done, but then a good deal has been said"; I think he meant by Congress, for he adds:

> The facts are these: They have a small observatory in process of erection at Tuscaloosa, Alabama, for the use of the university in that place. Professor H pkins, of Williams College, Massachusetts, has a little establishment of the sort, and this is about all in that state—all in New England! The only other establishment in the United States, known to me, is that in the Western Reserve College, Hudson, Ohio, under the charge of Professor Loomis. Nothing of the kind at our national seat of government or anywhere near it! Even Harvard University, "with all its antiquity, revenue, science, and renown," has thus far failed, though it appears that they are breaking ground at Cambridge; a house or houses having been purchased and fitted up, and one of our "savans" is already engaged in a series of magnetic and other observations.

Let us trace in detail how this small but prophetic beginning was made.

The spirit of Rittenhouse continued to inspire the Philadelphia observers, and his followers made many contributions to the American Philosophical Society. The desire to erect a public observatory at Philadelphia was cherished by many. In 1817, we find that the city granted to the society a building or part of a building for an observatory. Two pages of the Transactions[15] under the caption, "Philadelphia observatory," are devoted to a description of the building, the ordinance of the city council making the grant, and an appropriate resolution of sincere acknowledgments by the society. The building was located at the Center Square and was known as the Center Engine House. Only certain parts of the building were offered for the use of the society as an observatory, "to-wit, the south-east and north-west rooms in the basement story, together with the use of the passage between the said rooms; so much of the circular part of the said building as is above the basement story, and the roof of the said story." So far as we know, the said enactment produced no lasting results.

At Boston and at Harvard the scholarly successors of Winthrop carried on his scientific work. In 1780, Williams observed a solar eclipse and gave a good description of the phenomenon known

[14] *Athenaeum*, 555, 1840.

[15] Transactions of the American Philosophical Society, New Series, Vol. I, p. XVI, 1818.

as Bailey's beads 50 years before the time of Bailey. The organization of the American Academy of Arts and Sciences placed special emphasis upon practical knowledge. The labors of the astronomer were solicited; "particularly those observations and calculations which will serve to perfect the geography of the country, and improve navigation." It is not strange, therefore, to find that the astronomers were engaged by the government in the work of surveying, and the true spirit of observational work was retarded. Andrew Ellicott is perhaps the best example of a practical astronomer who served surveying. He contributed many astronomical papers to the learned societies, chiefly regarding observations made in connection with his boundary survey work. He also made some good observations of the comet of 1807 with a sextant of six-inch radius graduated by Ramsden. He sent some of his observations to Delambre, accompanying them with the explanation that they were made by "a self-taught astronomer, and the only practical one now in the United States." Such was the condition in 1816 that a friend of Comte in this country warned him against the purely practical spirit saying,[16] "If Lagrange were to come to the United States he could only earn his livelihood by turning surveyor." In connection with this kind of work, a so-called observatory was built on Capitol Hill in Washington about 1822 and was used by Lambert and Ellicott to determine the longitude of the place.

About the same time, 1823, W. C. Bond erected a small wooden building near his father's residence in Dorchester and equipped it with astronomical and meteorological instruments. Here systematic observations were made until Christmas day, 1839. His work also attracted the attention of the government and of the Harvard College Corporation.

The colleges of the country kept the spark of true astronomical fervor from complete extinction, and plans were in progress for the erection of observatories. At Harvard as early as 1805, Mr. John Lowell, then residing in Paris, consulted Delambre regarding observatories and procured written instructions which he transmitted to Professor Webber, one of the worthy occupants of the Hollis chair made prominent by the work of Winthrop. Ten years later, on May 10, 1815, it was voted by the college corporation "that the President (Dr. Kirkland), the Treasurer and Mr. Lowell, with Professor Farrar and Mr. Bowditch, be a committee to consider upon the subject of an Observatory." The services of W. C. Bond, who was just sailing for England, were solicited. He received a

[16] Cajori, "The Teaching and History of Mathematics in the United States," 94, 1890.

letter of instructions from Farrar, June 23, 1815, to obtain detailed information on observatories and equipment, when he was in Europe. Alas, the estimated cost of an establishment worthy of Harvard was too high and the project was again postponed. It was revived in 1822, and popular subscriptions began in 1823. J. Q. Adams, eloquent advocate of the need of a national observatory, pledged $1,000. Again the project failed.

After the time of Rittenhouse, up to the year 1830, notwithstanding the continued interest, nothing existed in the United States worthy of the name of an astronomical observatory, with the possible exception of Bond's at Dorchester. Suddenly the rapid rise of observatories began in America and soon the "lighthouses of the sky" dotted the hilltops along the Atlantic from Massachusetts to Carolina and penetrated inland as far as Ohio and Michigan.

According to Professor James L. Love,[17] North Carolina University deserves credit for erecting the first college observatory in this country. In 1824, Dr. Caldwell, the president of the university, was sent to Europe to buy books and apparatus. Among the instruments purchased in London were a meridian transit instrument and a zenith telescope made by Simms, a refracting telescope by Dolland, an astronomical clock by Molyneaux, a sextant by Wilkinson, a reflecting circle by Harris and a Hadley's quadrant. These instruments were used in the university buildings and on the roof of the president's house until 1831, when they were placed in an observatory which had just been built for them. F. P. Venable,[18] in his historical sketch, gives 1830 as the date of the erection of the building. The observatory was of brick and stone, about 20 feet square and 25 feet high. It had a well-constructed pier and was covered by a flat roof with a slit. Here instruction was given and observations were made by President Caldwell and Professors Elisha Mitchell and James Phillips. Shortly after the death of Caldwell in 1835, the instruments were removed on account of leakage in the roof. Bricks were carried away to use in building a kitchen for the new president. The observational records were lost. The instruments were quietly laid aside, and it is said that Sherman's soldiers found that the tube of the old telescope on a dusty shelf was selected by some of the professors as the safest hiding place for their watches and other valuable possessions.

At Yale University a more successful astronomical movement was in progress. In 1828, Mr. Sheldon Clark donated $1,200 for the purchase of a telescope, which arrived from Dolland, of London, in the year 1830. It had a 5″ object glass with a focal length of 10

[17] *The Nation*, August 16, 1888.

[18] *Sigma Xi Quarterly*, September, 1920.

feet. No building was provided, so it was placed in the tower of one of the college buildings. Without permanent mounting and lacking graduated circles, nevertheless, in the hands of Professors Olmstead and Loomis, it acquired a great reputation. The return of Halley's comet in 1835 was observed by them long before news arrived of its observation in Europe. The division of Biela's comet was first observed by Herrick and Bradley with the same instrument. Olmstead succeeded in creating great enthusiasm for astronomy and drew about him a strong group of men who assisted in ushering in the new era of astronomy in America. Loomis, Chauvenet, Stanley, Mason, Lyman and Twining owed their inspiration to him. His text-book on natural philosophy ran through no less than 100 editions. Although the astronomical work at Yale was very successful, no building was provided for an observatory within the period under discussion. Loomis,[19] in his excellent list of American observatories, gives first place to Yale, fixing the date at the time of the arrival of the Clark telescope in 1830.

We wish to give special emphasis to a structure entirely omitted by Loomis. Its astronomical nature was partly concealed by the name of "Depot of Charts and Instruments," which was established in 1830; but the building in which we are now interested was not erected until 1833. A boy of 15 entered the navy as midshipman. Of studious habits he advanced rapidly and soon received the grade of passed midshipman. Overhearing a remark by a member of Congress that "there is not an officer of the navy capable to conduct a scientific enterprise," he set to work to disprove it in his own case. When James M. Gilliss was ordered to Washington in 1836 as assistant to Lieutenant Hitchcock, in charge of the Depot of Charts and Instruments, he entered a small building 13′ x 14′ erected by Lieutenant Wilkes in 1833 in the vicinity of his own residence, about 1,200 ft. north of the Capitol. A 4″ transit borrowed from the Coast Survey was the chief instrument. Gilliss was set at work rating the chronometers and making sextant and circle observations. Soon he was placed in charge of this establishment and began his remarkable career. In the winter of 1837–38 he observed a series of moon transits and star occultations for longitude in connection with survey work. In 1838 the Wilkes exploring expedition started on its mission and Gilliss was ordered to remain in Washington and to continue observations. "From that time" (September, 1838), says Gilliss,[20] "till the return of the expedition in 1842, I observed every culmination of the moon, and

[19] Elias Loomis, "The Recent Progress of Astronomy," Third Edition, 1856. The author is greatly indebted to this work for much of the material that follows.

[20] Senate Report, No. 114, 28th Congress, 2nd session, 65.

every occultation visible at Washington, which occurred between two hours before sunset and two hours after sunrise. . . . The number of transits recorded exceeds 10,000, embracing the moon, planets and 1,100 stars. The average annual number of culminations of the moon observed was 110 and of lunar occultations about 20."

Gilliss's volume of astronomical observations was the first published in the United States. When Gould asked another astronomer whether the published observations were good and creditable to astronomy in America, he received the reply: "Yes; they are very good, too good for Gilliss's reputation. No man could have made such good ones." Professor Peirce tested the original records by the law of probabilities and vindicated both the truthfulness and the accuracy of the observer. Walker also tested the work and stated that he found only one astronomer, Argelander, whose transit observations manifested precision equal to those of Gilliss's. Not in consideration of the size of the building, nor the height of its dome, not by virtue of the cost of its instruments, nor to any superficial display, do we include Wilkes's observatory, as it was called; but from the standpoint of the results obtained by a faithful and unrewarded observer, we believe this building deserves an honorable mention among the early American observatories.

Williams College Observatory, Massachusetts, next claims our attention. Loomis calls this the first attempt to found a regular astronomical observatory in this country. In 1836, Professor Albert Hopkins erected a stone building, about 20′ by 48′, consisting of a central part and two wings. The central part was surmounted by a revolving dome 13′ in diameter under which was a Herschelian telescope of 10′ focal length mounted equatorially with graduation circles which read to minutes. A 3½ inch transit by Troughton and a compensation clock by Molineaux were also provided.

And now we begin our westward course. The next observatory was in connection with Western Reserve College, Hudson, Ohio. Professor Loomis went to Europe in 1836 to purchase instruments and returned the following year with an equatorial telescope by Simms with an aperture of four inches and 5½ feet focal length, and a 3-inch transit with graduated circle with microscopes reading single seconds. The clock by Molineaux had a mercurial pendulum. A convenient building, 16′ by 37′, was provided and the instruments were installed in 1838. Moon culminations for longitude, culminations of Polaris for latitude and star occultations formed the early observational program. Five comets were also observed for orbital determination.

The Philadelphia High School Observatory was erected at about the same time as Western Reserve. When the Central High School

was established, a sum of $5,000 was set aside for an observatory. In 1838, a tower 45 feet high was erected in the rear of the school building. It is insulated 10 feet below the surface and is 12 feet in diameter. It is surmounted by a dome 18 feet in diameter and contains an equatorial telescope of 8 feet focal length and six inches aperture by Merz and Mahler of Munich, which is moved by clockwork. The erection of this observatory marked the beginning of the introduction of better equipment. Observations by Walker and Kendall attracted attention not only in this country but also in Europe. Their cometary observations were noteworthy, especially those of the great comet of 1843.

In 1839, there was erected an observatory at West Point. The large building was intended also for a library and contained philosophical apparatus. It had three towers for astronomy. The central tower was surmounted by a dome 27 feet in diameter. In 1840 Professor Bartlett visited European observatories and returned with instruments. The equatorial telescope, of 8 feet focal length and six-inch aperture, was made by Lerebour, of Paris. From this institution came Courtenay, Norton, Mitchel and Bartlett.

Soon after the erection of the observatory at West Point, the National Observatory was erected at Washington. The origin of this observatory may be traced to the needs of the naval service. The work of Gilliss had prepared the way in a more effective manner than the memorials of Lambert and the eloquent appeals of Adams. In 1842, he was instructed to prepare plans for a building. We can not go into detail to show how well the task was done. With some improvements suggested by European astronomers, the plans were adopted and Gilliss supervised the construction. Excellent equipment was provided and the institution was ready for work. On October 1, 1844, Lieutenant Matthew F. Maury, a young officer without scientific education or experience, and with small scientific pretensions, was appointed superintendent. Gilliss, who had a right to expect appointment, merely said, "It was hard, but an officer must obey orders and not find fault with them." An efficient staff was selected, however, among whom we find Walker, Hubbard, Coffin, Ferguson, Keith and Yarnall.

The Georgetown Observatory was begun in 1843, and finished in 1844. The central part was 30 feet square, with two wings, each 15′ x 27′. The chief instruments were an equatorial telescope with a 5″ lens by Simms, a 4½″ transit by Ertel and Son, of Munich, a 4″ meridian circle by Simms, and a sidereal clock by Molineaux.

And now we come to the Cincinnati Observatory, which excelled them all. This "temple of astronomical science," as it was proudly

and appropriately called by a citizen of Cincinnati,[21] was established by an organization of the people, by the people, and for the people, made possible by the magnetic leadership of Ormsby MacKnight Mitchel and the generosity of his fellow-citizens. Cincinnati may be justly proud of this achievement, the erection by the people of the first great astronomical observatory, not only in America, but in the whole world.

Mitchel was born at Morganfield, Union County, Kentucky, August 28, 1809, but the greater part of his life was spent in Ohio. His primary education was received at Lebanon, Ohio, and at 13 he was a clerk in a country grocery store at Miami. At the age of 16 he was appointed to West Point and graduated in 1829, a classmate of Robert E. Lee and Joseph E. Johnson. Then followed a few years of checkered career. He was assistant professor of mathematics for two years, then he was assigned to military service at Fort Marion, St. Augustine, Florida. We next find him in Cincinnati, where he studied law and was admitted to the bar. He practiced law and was chief engineer of the Little Miami Railroad. And then he found his post, or rather the place found him. In 1834, at the early age of 25, he was appointed professor of mathematics, philosophy and astronomy, in the newly established University of Cincinnati. In the winter of 1841–42 he accepted an invitation to deliver a course of lectures on astronomical subjects before the Society of Useful Knowledge. The beauty and sublimity of his style may be illustrated by a brief passage:[22]

> The starry heavens do not display their glistening constellations in the glare of day, while the rush and turmoil of business incapacitate man for the enjoyment of their solemn grandeur. It is in the stillness of the midnight hour, when all nature is hushed in repose, when the hum of the world's on-going is no longer heard, that the planets roll and shine, and the bright stars, trooping through the deep heavens, speak to the willing spirit that would learn their mysterious being.

His lectures were received with great enthusiasm, and at their close he announced his determination to secure for the people of Cincinnati an astronomical observatory equal in instrumental equipment with the best in the world. Miss Clerke, English historian of astronomy, gives great credit to Mitchel in her unique way. She says:

> The organization of astronomy in the United States of America was due to a strong wave of popular enthusiasm. In 1825, John Quincy Adams vainly urged upon Congress the foundation of a national observatory; but in 1843 the lectures on celestial phenomena of Ormsby MacKnight Mitchel stirred an im-

[21] Charles Cist, Sketches and Statistics of Cincinnati in 1851.
[22] "The Planetary and Stellar Worlds," 17, 1863.

pressionable audience to the pitch of providing him with the means of erecting at Cincinnati the first astronomical establishment worthy the name in that great country.

Mitchel organized the Cincinnati Astronomical Society, the first popular organization of its kind, with its heterogeneous membership, including literally doctor, lawyer, merchant, and we were about to add chief, rich man, poor man, beggar man, thief. He classified the membership under 67 professions and vocations, and adds: "Remainder unknown." He proposed to raise $7,500.00, in shares of $25 each, every subscriber to be a member and entitled to the privileges of the observatory. On November 9, 1843, the corner-stone of the observatory was laid by the venerable John Quincy Adams,[23] then 77 years of age. His eloquent oration on that occasion was one of the last public acts of his noble life. You may recall his rebuff by Congress nearly 20 years before. Here was his opportunity. He lamented the apathy of the nation toward the claims of astronomical science and congratulated the citizens of Cincinnati on the fact that their generosity and enthusiasm had at length wiped the reproach from the fair fame of their beloved country.

Here is where Mitchel's difficulties began. Only $3,000 out of the $9,500 pledged had been paid in. An additional sum of $6,500 was necessary to pay for the telescope alone, and Mitchel was appointed collector. Concerning this work, he says:

> A regular journal was kept of each day's work, noting the number of hours employed, the persons visited, those actually found, the sums collected, the promises to pay, the positive repudiations, the due bills taken, payable in cash and trade, and the day on which I was *requested to call again*. . . . By systematic perseverance at the end of some forty days the sum of $3,000 was paid over to the Treasurer, as the amount collected from old subscribers. Nearly two thousand dollars of due bills had been taken, payable in carpenter work, painting, dry-goods, boots and shoes, hats and caps, plastering, brick-laying, blacksmith work, paints and oils, groceries, pork barrels, flour, bacon and lard, hardware, iron, nails, etc., in short, in every variety of trade, material and workmanship.

$3,500 were yet required to pay for the telescope. The sum was raised by well-directed personal canvass for subscriptions among the more wealthy members. But where was the building to come from?

A magnificent site of four acres was donated by Nicholas Longworth, on the summit of Mt. Auburn, afterward named Mt.

[23] Jermain, G. Porter, "Historical Sketch of the Observatory of the University of Cincinnati, 5, 1923."

Adams, about five miles east of the city, at an elevation of 500 feet above the river. Mitchel went to work without a dollar in the treasury to construct the building. He hired laborers by the day, beginning with a force of two masons and one tender, all that he could afford to pay on Saturday night. The next week the force was doubled and soon increased to 50 men. He says: "Each Saturday night exhausted all my funds, but I commenced the next week in the full confidence that industry and perseverance would work out their legitimate results." The exorbitant cost of delivering material on the hill made it necessary to quarry limestone on the site, to build and fire a lime kiln, to open a sand pit, and to dam a ravine to get water. During all this time Mitchel continued his duties as professor in the university, often spending five hours a day in the classroom. Finally, the building was completed, a magnificent structure about 30′ by 80′.

At an earlier date (1842) Mitchel planned to visit Europe to purchase a telescope. He called upon President Tyler in the hope of securing letters of introduction to European sovereigns and savants; but received an indifferent response. John Quincy Adams, ex-president, gave him the desired credentials. He found an object glass of nearly 12 inches diameter and 17½ feet focal length, at the Frauenhofer Institute, Munich, made by Mertz and Mahler. It had been tested by Dr. Lamont and pronounced one of the best ever manufactured. This is the instrument for which he paid $9,437 in hard-earned cash. It arrived in February, 1845, and was soon ready for work. Equipped with eye-pieces to vary the magnifying power from 100 to 1,400, well-graduated declination and hour circles with verniers reading to 4 seconds and 2 seconds, respectively, and an excellent driving clock, it might seem as though Mitchel's troubles were at an end, excepting the trifling consideration that he had agreed to act as director for ten years without salary. He devoted much of his time to the remeasurement of Struve's double stars south of the equator. A number of interesting discoveries were made. Some stars previously marked as oblong were separated; others marked double were found to be triple, while his observations, combined with Struve's, demonstrated the fact that many of the stars are physical binaries.

But scarcely had Mitchel's observatory been completed when the college building burned and his salary as professor ceased. Unable to live on his salary as director, he again took to the lecture field and at one time to railroad engineering. But it was not for selfish motive or lack of astronomical zeal. His undaunted courage, unflagging energy and persistent perseverance mark him as one of astronomy's most loyal devotees, and one of the nation's most honored sons.

At the time our story ends in 1848, the Cincinnati observatory was playing an important part in the development of the chronographic method of recording time signals and in its application to the so-called American method of longitude determination.

We noted the postponed plans at Harvard to found an observatory and also mentioned the work of Bond in his private observatory at Dorchester.

> In October, 1839, the Harvard Corporation was informed that Mr. William Cranch Bond was engaged under an appointment and contract with the government of the United States, with a well-adapted apparatus, in a series of observations on meteorology, magnetism and moon-culminations, as also upon all the eclipses of the sun and moon and Jupiter's satellites, in connection with those which should be made by the officers of the expedition to the South Sea, commenced in 1838, under the authority of Congress, for the determination of longitude and other scientific purposes.[24]

It occurred to President Quincy, of Harvard, that, if Bond would transfer his instruments to Harvard and pursue his observations there, under the auspices of the university, it might facilitate the establishment of an observatory by the interest which his observations would arouse and by drawing the attention of citizens of Boston to the inadequacy of the means possessed by the university for difficult astronomical observations. Steps were taken to raise $3,000 for the purpose of altering a dwelling house owned by the college and known as Dana House, and adapting it for the use of Mr. Bond. An inventory of Harvard's apparatus at this time incudes an astronomical clock, unreliable; small transit, at one time loaned to Bowditch but returned because of little use; two reflecting telescopes, of two and three feet focal length and a quadrant. No more convenient place for using the instruments was available than an open field or a window which might accidentally open in the right direction. Bond brought to the Dana House a reflector of 30 inches focus, and an achromatic refractor of 40 inches focus, clocks, chronometers and magnetic apparatus. He was appointed director without salary, and yet the people did not respond.

The impulse towards awakening popular interest came from "the heavens itself." The unexpected appearance of the splendid comet of 1843 wrought the popular as well as the scientific mind into a state of excitement. It was a brilliant comet with a long train. The people of Boston naturally looked to the astronomers at Cambridge for information respecting its movements. The astronomers replied that they had no instruments. This announce-

[24] Quincy, "History of Harvard University," Vol. II, 391, 1860.

ment, together with the knowledge that good instruments were in existence in other parts of the United States, aroused the determination to supply the deficiency. Definite action was taken in March, 1843. The corporation of Harvard University purchased an excellent site of six and one half acres, for the erection of an observatory. Elevated 50 feet above the university campus, it commanded in every direction a clear horizon, without obstruction from trees, houses, smoke or other causes. Upon this site, known as Summer House Hill, the Sears Tower was erected for accommodation of the large telescope, with wings for the other instruments, and a residence for the director. The central tower is 32 feet square, built of brick, resting on a granite foundation, and is surmounted by a circular dome 30 feet in diameter. Here is mounted the 15-inch telescope, which arrived in 1847, another product of the Munich firm. It equalled, not only in size, but also in optical efficiency, the great refractor of the Russian national observatory at Pulkowa. These two "grand refractors" were the largest and most efficient in the world at the close of the period under discussion.

Immediate success followed the use of the large refractor. On September 17, 1848, Bond discovered Hyperion, the eighth satellite of Saturn, two days before it was seen by Lassell. This was the first addition to the solar system discovered in America. In 1850, it was followed by the discovery of Saturn's dusky ring. The work of the Bonds on solar and stellar photography and the resolution of nebulae with the Harvard apparatus would take us beyond the limits of our assignment.

Following the Cincinnati observatory, others were erected in rapid succession. Private individuals as well as colleges took part in the movement. Sharon observatory, a private establishment, was erected by Mr. John Jackson about seven miles west of Philadelphia. Its chief instrument was a 6 1/3″ refractor by Merz and Son, of Munich. Here we find American instrument makers beginning to play a part in the construction of equipment. The meridian circle was made by Young, of Philadelphia, only the object glass having been imported. The sidereal clock was made by Grokengiesser, of Philadelphia. In the upper part of the city of New York was the private observatory of Lewis M. Rutherford. It contained a 9″ refractor made in America by Henry Fitz, of New York. It was at this time also that Alvan Clark began his work, which soon made American objectives the most efficient in the world.

We can mention only by name the observatory of the University of Alabama, erected in 1843, although the telescope was not received until 1849, an 8″ by Simms; the Friends Observatory, Philadelphia,

built in 1846, provided with a Fitz 5″ objective; Amherst College Observatory, erected in 1847, where a 7¼″ Clark lens was later installed; Charleston Observatory, South Carolina, built by Professor Lewis R. Gibbes in his own garden; Dartmouth College Observatory, with an excellent 6″ equatorial by Mertz and Sons and other good equipment. Plans for observatories were in progress at a dozen other places.

By 1848, just 16 years after Airy made his statement concerning the lack of observatories in the United States, and just eight years after the London *Athenaeum* remarked that much had been said, but nothing had been done, we find about 20 observatories worthy of the name; and two of the number, the Cincinnati Observatory, representing the people, and the Harvard Observatory, representing the university, occupied a place among the best equipped observatories of the world. In 72 years after the birth of the republic it was ready to contribute its share in observational work and in astronomical discovery by the side of the nations of the earth in which astronomy had been cultivated from the dawn of civilization.

# PARASITISM AMONG THE PROTOZOA

By Professor ROBERT W. HEGNER
THE JOHNS HOPKINS UNIVERSITY

## (1) Animal Habitats and Types of Association among Protozoa

The earth offers various types of habitats for animals. The larger divisions usually recognized are (1) terrestrial, (2) fresh-water, (3) marine and (4) combinations of these. Most of the animals, however, that are of interest to medical zoologists have one characteristic in common—an intimate association with other organisms. Such animals do not belong in any of the above-named major habitats, but live upon or within the bodies of other animals and plants. Animals of this type have often been considered as living in the same habitats as their hosts, but it is obvious that their environment is radically different and that other types of habitats must be recognized to accommodate them. Various terms have been coined for the purpose of classifying the different types of association that exist among these organisms, but no single term is available that includes all of them. The word ectozoic has been employed for those that live on the outside of the body of the host, and the word entozoic for those that live within the body. The term parasitic usually serves to include both ectozoic and entozoic forms, and this usage may be considered correct when these organisms are discussed in popular language; but parasitism in its narrow sense involves a distinct disadvantage to one of the members of a pair of associated animals, *i.e.*, one animal, the parasite, lives on or in and at the expense of another animal, the host.

When species of Protozoa become associated with other animals or plants a large number of conditions may exist:

(1) The two members of the association may be mutually and equally beneficial.

(2) One member may secure a greater advantage than the other without either undergoing any disadvantage.

(3) One member may live more or less at the expense of the other without causing any injury to the body.

(4) One member may injure the body of the other but not enough to produce clinical symptoms unless present in large numbers.

(5) One member may be pathogenic to the other, *i.e.*, may give rise to a diseased condition. The disease produced may be mild and only a contributing cause of death or may be severe and the direct cause of death. Often one species of protozoan parasite may be lethal under certain circumstances and non-lethal under others.

The advantages gained by these associations are usually concerned with two of the most important fundamental requirements of all animals, namely, protection and food, and the character of the association is more largely influenced by the latter. The principal methods of nutrition exhibited by Protozoa are (1) holozoic, which implies the capture and ingestion of solid particles of food, (2) holophytic, which involves the elaboration of food by photosynthesis, as in plants, and (3) saprozoic, which means living on decomposing organic matter. Many Protozoa, both free-living and ectozoic or entozoic, employ several or all three of these methods of obtaining food. Thus an intestinal amoeba, like *Endamoeba histolytica,* may ingest red blood cells (Fig. 1, A) and other tissue elements, and may also absorb material through the surface of the body. This material may be decomposed organic matter or may be organic material prepared for digestion by the host. The term saprozoic, in the opinion of certain students, covers both the absorption of decomposed organic material and of digested substances, but is really limited by its etymology to the absorption of decomposed organic material and another term should be used for the absorption of digested substances. Frequently the term "parasitic nutrition" is employed, but this is bad usage, since parasites are not characterized by any definite method of nutrition but by one or a combination of the methods just described, that are common to free-living organisms as well.

Several of the types of associations that occur frequently among Protozoa are distinct enough so that definitions are possible; these are commensalism, symbiosis and parasitism. One partner may be a protozoon and the other a plant or both may be Protozoa.

*Commensalism* is applied to an association in which one partner is benefited whereas the other is neither injured nor benefited. The former is the commensal, the latter the host. How frequent such associations are among the Protozoa it is difficult to state, since it seems probable that if examined carefully enough the host will always be found to suffer some injurious effects from the association. For example, the flagellate, *Trichomonas* (Fig. 1, C), feeds chiefly on waste food products and bacteria within the intestines of its host, but it probably also absorbs through its body wall digested products of *use* to its host. When present in small numbers or when the host has an abundance of food the absorption of this material is probably of no importance to the host, but it may become a real menace when food is scarce and millions of the flagellates are present. The term "food-robber" has been used by Minchin to include species that feed on material in a more or less digested condition.

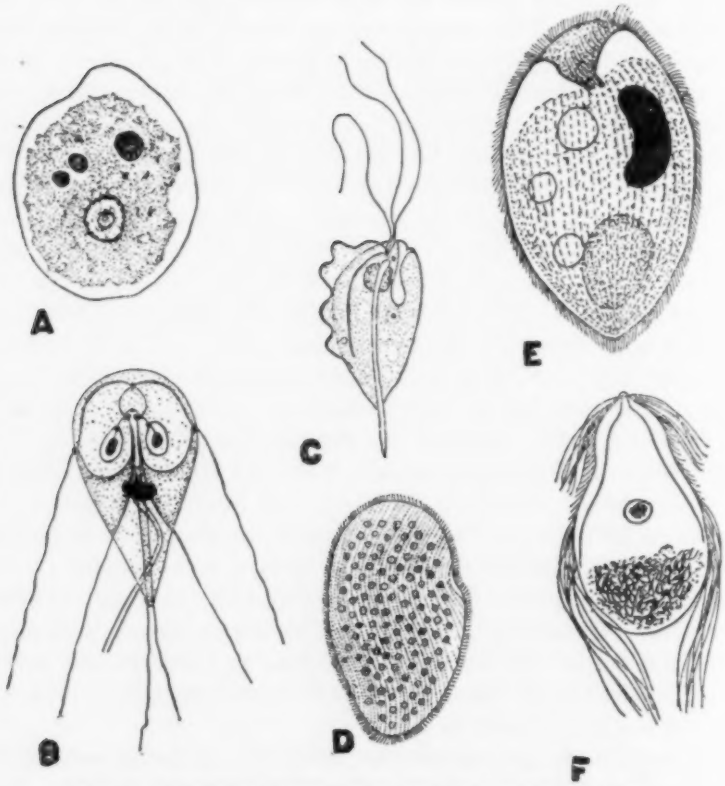


FIG. 1. PROTOZOA PARASITIC IN THE INTESTINE OF MAN AND LOWER ANIMALS

A. *Endamoeba histolytica*, the causative agent of amoebic dysentery in man. A nucleus and three red blood cells are visible.
B. *Giardia lamblia*, supposed to be a causative agent of flagellate diarrhea. The upper portion of the body is a sucking disc.
C. *Trichomanus hominis*, another supposed causative agent of flagellate diarrhea.
D. *Opalina ranarum*, a ciliate parasitic in the frog. No organelles are present for the ingestion of food.
E. *Balantidium coli*, a ciliate that causes dysentery in man.
F. *Trichonympha campanula*, a flagellate living in the digestive tract of termites. Wood particles are present in the posterior end.

(A, after Dobell; B, after Simon; C, after Faust; D, original; E, after Leuckart; F, after Kofoid and Swezy.)

*Symbiosis* is an association of two species of animals that benefits both parties. Sometimes the partnership is of such a nature that neither member can live without the other. An excellent example of this type has recently been described by Cleveland. This investigator finds that wood-eating termites starve to death on their usual diet of wood if they are deprived of their intestinal flagellates

(Fig. 1, F). Food in a partly digested condition defecated by the termites is fed to their offspring, thus passing on the infection from one generation to the next. The flagellates as well as the termites are enabled to continue in existence by this unique method of infection. In other cases, either partner can exist alone, but there is apparently an advantage to both in being associated. This is true of the association between certain Protozoa and algae. Thus *Paramecium bursaria* may live what we think of as the normal life of a free-living ciliate unless it chances to ingest certain algae. These spherical algae are at first contained in a regular food vacuole, but, instead of being digested, are soon brought into intimate contact with the protoplasm due to the disappearance of the liquid within the vacuole. They then divide and form a layer of symbiotic algae. Both the paramecia and the algae can live successfully alone but appear to be benefited by their symbiotic association.

As already stated, *parasitism* is popularly applied to any association in which one species lives on or within the body of another species. In this sense it includes many cases of commensalism and symbiosis. In a more restricted sense, however, it is simply an advanced type of commensalism in which the injury to the host is obvious. The terms ectozoic and entozoic, rather than the term parasitic, should be applied to species that live on the surface without injuring the host, or within the host but are not known to be injurious.

### (2) Extent of Parasitism among the Protozoa

If we use the term parastism in its broadest sense, this condition exists in every large group of the Protozoa. One of the four classes into which the Protozoa are usually divided, the Sporozoa, contains nothing but parasitic species, and each of the other three classes numbers among its members many parasitic forms. It is impossible to state how the free-living and parasitic forms compare in number of species, but it seems safe to assert that there are at least as many species living on or within other animals as there are free-living species. This large number of parasitic species is correlated wth the fact of specificity of parasite and host, since frequently each species of host is parasitized by its own particular species of parasites. Furthermore, there are probably very few species of the higher animals that are not parasitized by more than one type of protozoon. A few examples will indicate the actual conditions.

Kofoid examined 5 species of Amphibia, 4 species of reptiles, and 6 species of mammals for intestinal flagellates, a total of 15 species. Flagellates were found in every species studied and in

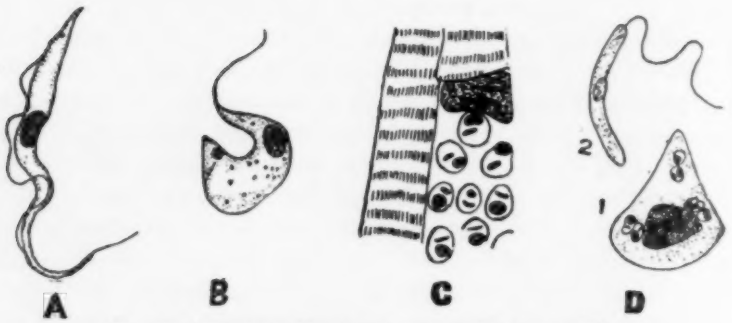


FIG. 2. PROTOZOA PARASITIC IN THE BLOOD OF MAN

A. *Trypanosoma gambiense*, the causative agent of African sleeping sickness.
B. *Trypanosoma cruzi*, the causative agent of Chagas' disease in South America. Stage occurring in the blood.
C. *T. cruzi*. Stage occurring in muscle.
D. *Leishmania donovani*, the causative agent of kala-azar. 1. Stage occurring in tissue. 2. Flagellate stage.
(A, after Castellani and Chalmers; B, C, originals; D, 1, after Brumpt; D, 2, after Row.)

all but 2 per cent. of the 329 individuals examined. But more than one species of intestinal flagellate was present in each host species; for example, the salamander, *Diemyctylus torosus*, was found to harbor 14 species of flagellates belonging to 10 genera. Furthermore, these animals may have been infected with blood-inhabiting flagellates as well as with intestinal flagellates; with Sporozoa of various types; with intestinal ciliates; and with intestinal amoebae.

In a number of cases one species of animal has been studied rather carefully for parasites. This is of course true of man and to a certain extent of domestic and lower animals. On the basis of such studies we can judge fairly well the abundance and number of species that really exist. In man, for example, we know five distinct species of amoebae, five species of flagellates, four species of coccidia, one ciliate, three species of malarial organisms, three species of trypanosomes, and three species of leishmanias—a total of 24 species of Protozoa. Besides these, are a large number of species that have been described but not yet definitely established.

There is no reason to believe that man is affiliated with more numerous species of parasites than are certain other vertebrates; a large number of species has been recorded from man because he has been more carefully studied.

### (3) LOCATION OF PARASITIC PROTOZOA WITHIN THE HOST

The location of these organisms within the host may or may not be definite, but usually is. For example, one species of human

amoeba lives in the mouth, the others in the intestine, and different parts of the intestine may be the habitat of different species. One species, ***Endamoeba histolytica*** (Fig. 1, A), frequently finds its way into the liver and other parts of the body. The flagellates are mostly either intestinal or blood inhabitants, each species being rather definitely restricted to certain parts of the body. For example, ***Giardia lamblia*** (Fig. 1, B) is located in the duodenum, ***Trichomonas hominis*** (Fig. 1, C) in the large intestine, *Trypanosoma gambiense* (Fig. 2, A) in the blood, one stage of *Trypanosoma cruzi* (Fig. 2, B, C) in the blood, the other stage in the heart muscle, and *Leishmania donovani* (Fig. 2, D) in the tissues, particularly the spleen and liver. The coccidia are tissue parasites living in the epithelial cells lining the intestine or in the liver; the malarial organisms (Fig. 3) inhabit principally the blood cells, spleen, bone marrow, liver and brain, and the three species differ somewhat in their distribution within the body; segmenting stages of the estivo-autumnal parasite, for example, do not occur in the peripheral blood; the ciliate, ***Balantidium coli*** (Fig. 1, E) is restricted to the intestine although, unlike the flagellates, it may also become a tissue parasite.

When one studies the life-history of any of these protozoan parasites, it seems in many cases as though the parasite deliberately migrates to its definitive location, so perfectly is it adjusted to its complex environment. The sporozoite (Fig. 3, A) of the malarial organism seems to seek out a human red-cell; the gametocytes (Fig. 3, D, E) that later develop circulate about in the blood stream waiting to parasitize any anopheline mosquito that chances to bite its host; after fertilization (Fig. 3, F) has taken place the resultant ookinete (Fig. 3, G) recognizes the wall of the mosquito's stomach as an advantageous place for further growth and immediately creeps toward and penetrates its epithelial cells; and the sporozoites when they escape from the oocyst (Fig. 3, H, I) into which the ookinete develops make their way as rapidly as possible to the salivary glands where they lie in wait until they are given an opportunity to invade the blood stream of the human being the mosquito-host is biting. As a matter of fact, there are no such anthropomorphic qualities ascribable to parasitic Protozoa, the apparent selection of a satisfactory location at each stage in the life-cycle and the other activities of the organism having evolved through the operation of the same natural laws that are accountable for adaptations in all other living things.

### (4) Specificity of Host

The character of the host is probably also to be explained not by selection on the part of the parasite but by the operation of natural

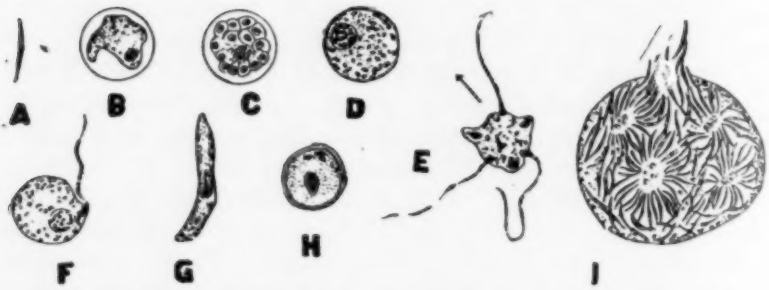


FIG. 3. STAGES IN THE LIFE-CYCLE OF THE HUMAN MALARIA PARASITE, *Plasmodium vivax*

A. Sporozoite ready to parasitize a red cell.
B. Trophozoite within a red cell.
C. Trophozoite undergoing reproduction by schizogony.
D. A female gametocyte.
E. A male gametocyte forming reproductive bodies (gametes).
F. Fertilization of a female gamete by a male gamete.
G. Ookinete.
H. Oocyst.
I. Ripe oocyst liberating sporozoites.

laws. The apparent selection of one species of host by one species of parasite is a very common occurrence among the protozoa. Perhaps the ectozoic forms are less particular than entozoic species. The ciliate, *Trichodina* (Fig. 4, B) for example, creeps about on the surface of *Hydra*, but appears to thrive equally well on tadpoles and planarians. In certain of the Suctoria all grades of host-selection have been noted: certain species attach themselves to almost any object either living or lifeless; others commonly are found attached to plants, such as *Discophrya cothurnata* to the leaves of *Lemna;* some prefer snails, others, Protozoa, water insects, hydroids or Crustacea; in some cases any part of the body of the host is apparently satisfactory, but frequently only one particular region is selected. For example, *Dendrocometes paradoxus* always is found attached to the branchial plates of *Gammarus*.

Entozoa, as a rule, seem to practice an even more rigid selection than ectozoa and not infrequently a genus will have a different species in each of a number of host-species. This is not always true, however, since in many cases a single species of parasite may occur in many species of hosts. An example of rigid specificity of host is afforded by the genus *Giardia* (Fig. 1, B.) Measurements and a careful study of the structure of giardias from various mammals indicate that constant differences of specific rank are present in different hosts. On the other hand, it has recently been shown by Becker that the flagellate, *Herpetomonas muscae-domesticae,* in-

habits the alimentary tract of at least six species of muscoid flies belonging to six different genera—an excellent example of non-specificity of host.

### (5) The Effects of a Parasitic Existence on the Parasite

The parasitic mode of existence has brought about modifications in structure and life-cycles that are worthy of the most careful study of any investigator. Many of these modifications are peculiar to particular genera or species, but others are more or less characteristic of entire groups of parasites and take the form of both simplification and complication. Degeneration of the organs of locomotion is a very common phenomenon among parasites; the members of the class Sporozoa are almost entirely devoid of the powers of locomotion, this function being taken over by the hosts which transport the parasite from place to place, and even transmit it from one host to another without any effort on the part of the parasite. The organs of nutrition are also often modified or lost; this probably does not occur as frequently in Protozoa as in the Metazoa. The Protozoa that are called "food-robbers" usually retain organelles for capturing and ingesting food particles—*Trichomonas hominis* (Fig. 1, C) is an example, with its well-developed flagella, cytostome and food vacuole mechanism. The normal condition for parasites, however, is life in an organic medium from which food is absorbed through the surface of the body; such an existence is often correlated with the absence of organelles for capturing and ingesting food particles; an example is the ciliate *Opalina* (Fig. 1, D) that occurs in the rectum of the frog. It is of course possible that the ancestors of *Opalina* may never have possessed these organelles, but it is probable that they were once present and have disappeared by a process of degeneration.

Some of the most complicated structural modifications have resulted from the necessity for maintaining some means of attachment to the host. *Trichodina* (Fig. 4, B) possesses a complicated cirelet of rods and hooks that prevent it from being washed off from its host. *Giardia* (Fig. 1, B) has a sucking disc that serves the same function within the intestine of its host. Stalks, suckers and adhesive organs of various types are common among the Protozoa, evidently having evolved during the development of the parasitic habit.

The modifications mentioned thus far deal with the condition of the individual parasite. Others are concerned with the maintenance of the race. Chief among these is the increase in the powers of reproduction made necessary because of the very hazardous

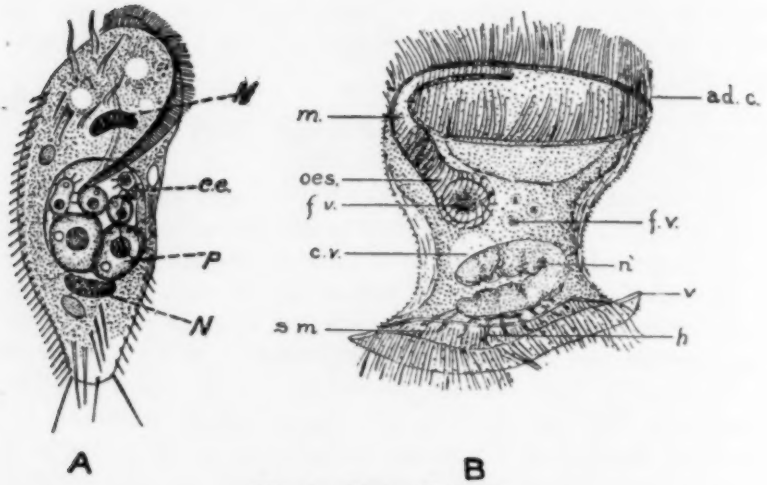


FIG. 4. CILIATE PROTOZOA

A. A protozoon parasitized by another protozoon. *P.*, parasite; *c. e.*, young parasite; *N*, nucleus. (After Stein.)

B. *Trichodina pediculus*, an ectoparasite on *Hydra*, tadpoles, etc.; *ad. c.*, adoral cilia; *c. v.*, contractile vacuole; *f. v.*, food vacuole; *h.*, hooks; *m.*, mouth; *n.*, macronucleus; *oes.*, oesophagus; *s. m.*, striated membrane; *v.*, velum. (After Clark.)

period during which the parasite leaves one host and becomes established within another. Simple binary division is usually all that is necessary to maintain the numbers of free-living Protozoa, but in many parasitic species certain types of sporulation (Fig. 3, C, I) have apparently evolved concurrently with the evolution of the parasitic habit, and these processes increase tenfold or more the possible number of offspring.

### (6) LIFE CYCLES OF PARASITIC PROTOZOA

The principal stages in the life cycles of parasitic Protozoa that may be correlated with the parasitic habit are those that result in an increase in numbers of individuals; in changes made necessary for life within or upon other animals; in structural modifications for protection during the passage to new hosts; and in the adaptations for securing transmission from one host to another.

In the first place, it may be worth while to point out that we really know comparatively little about the life-cycles of either free-living or parasitic Protozoa; as a matter of fact we probably know more about the parasitic than about the free-living species. The elaborate life-cycles described and pictured in various text-books and original papers on protozoology should not be taken too seriously, however, since many of the details are obviously incorrect.

It is the custom to determine as many stages as possible by morphological methods from material collected more or less at random, and then fit them together into as orderly a cycle as possible. The result is only an approximation of the truth. Each cycle needs to be studied as a living continuous series of intergrading processes: a study that requires the use of experimental methods, and infinite industry and care. For those who wish to carry on investigations in the field of protozoology there are numberless problems begging to be solved—problems that require research ability of the highest type, and involve practical considerations as well as phenomena of the greatest biological significance. There are even serious gaps in our knowledge of the malarial parasites of man after forty years of continuous study by many of the most able investigators.

The increased powers of reproduction of parasitic Protozoa are brought about in various ways; the most common are the interpolation of schizogony and sporogony into the life cycle. A gregarine, *Monocystis,* parasitic in the earthworm, is an example of a form that increases by sporogony only. Each individual produces many gametes; these fuse in pairs; each pair develops into a spore; and within each spore eight sporozoites are formed. Each sporozoite grows into an individual ready to produce gametes again if proper conditions are encountered. This entire life-cycle is passed within a single host. Certain other parasitic Protozoa multiply both by sporogony and by schizogony and pass through the former in one host and the latter in a different species of host. The malarial parasite of man, *Plasmodium vivax,* multiplies rapidly within the blood of man by schizogony (Fig. 3, C); each parasite produces from 15 to 24 merozoites without first conjugating with another parasite. Eventually gametocytes (Fig. 3, D, E) are formed which can only complete their destiny when taken into the stomach of certain species of mosquitoes of the genus *Anopheles.* Sporogony (Fig. 3, H, I) occurs in the mosquito and results in the production of enormous numbers of sporozoites (Fig. 3, I) that are ready to start a new cycle of schizogony if inoculated into the blood stream of a susceptible human being.

*Methods of escape from the host:* Certain stages in the life-cycles of parasitic Protozoa seem to have evolved so as to enable the organisms to escape from one host and infect new hosts. Species, such as those inhabiting the intestine and other organs provided with ducts, have no difficulty in reaching the exterior, passing out of the host in excretory or secretory material. Thus the cysts (Fig. 5) of intestinal amoebae, flagellates and coccidia are passively carried out of the body in this way. When the parasites inhabit closed cavities such as the coelom or blood spaces, or live in the tissues,

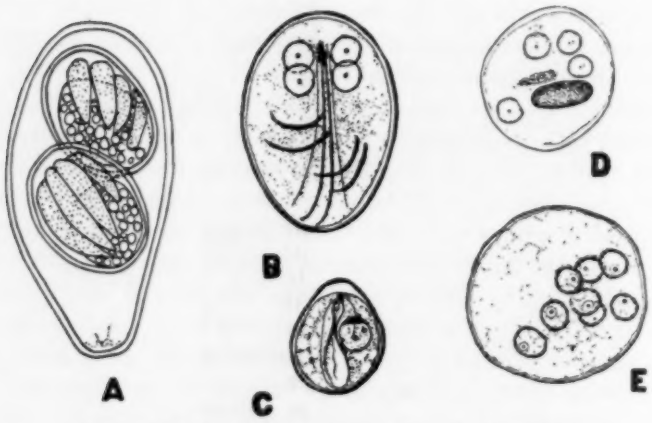


FIG. 5. SPORES AND CYSTS OF HUMAN PROTOZOA

A. Oocyst of a human coccidium, *Isospora hominis*, containing two spores, within each of which are four sporozoites.
B. Cyst of *Giardia lamblia*. (See Fig. 1. B.)
C. Cyst of *Chilomastix mesnili*, a human intestinal flagellate.
D. Cyst of *Endamoeba histolytica*. (See Fig. 1, A.)
E. Cyst of *Endamoeba coli*, a harmless amoeba living in man. (A, D, E, after Dobell; B, C, after Kofoid.)

greater difficulties are encountered and various methods of escape are employed. In some cases only the death of the host can possibly liberate the parasites; it is of advantage for this type of organism to cause the death of the host—a result that is actually accomplished by such tissue-infecting parasites as the Myxosporidia of fishes. The escape of the parasites and reinfection of new hosts may require the violent death of the host; this seems to be the case with the monocystis of the earthworm—the earthworm is eaten by birds through whose digestive tract the released spores pass unharmed; new hosts are infected by contamination of the food of the earthworm by the feces of the birds. The bird in this case can not be said to be parasitized. In other cases the host is eaten by another species of animal in which part of the life-cycle of the parasite takes place. Thus, in the case of the hemogregarine of the rat, the mite in whose body sporogony occurs is eaten by the rat in whose body the liberated sporozoites initiate schizogony.

Finally in some cases there seems to be no possible avenue of escape and we are forced to the conclusion that the parasites have entered a "blind alley" from which they never again emerge. The "blind alley" theory was proposed by Darling to account for the occurrence of Sarcosporidia (Fig. 6, D) in man, and is generally accepted at the present time.

*Methods of entrance into new hosts:* As all these cases indicate, escape is generally effected without any activity on the part of the parasite. In certain cases, however, the parasite actually migrates from one host and into another; this is true of *Trypanosoma equiperdum,* which causes dourine in horses. This species is supposed to make its way by its own activity through the mucous membrane of the host and during copulation of the host to penetrate the mucous membrane of another host.

A common method of entrance into new hosts is that of contamination. Races that are maintained in this way usually include in their life-cycles a resistant stage, which is most frequently a cyst or spore (Fig. 5) with a firm covering which impedes desiccation and prevents the entrance of deleterious substances. Such cysts and spores are widely scattered but do not undergo further development unless they reach a favorable environment. The chances of one of these cysts or spores reaching such an environment are so small that enormous numbers of them must be produced in order to prevent the race from dying out. This type of dissemination is the rule with intestinal amoebae, flagellates and coccidia, and among the Sporozoa in general. Among the vicissitudes encountered by cysts and sports of these species are (1) drying, (2) death due to the action of the bacterial mass in which they are embedded, and (3) death due probably to starvation in cysts and spores that reach an environment that is favorable in every way except as regards the presence of a new host. These cysts and spores must also be resistant to various excretions and secretions within the host, such as toxic substances in the fecal material before they leave the original host, and enzymes encountered within the anterior portion of the digestive tract of the new host, which makes it possible for them to reach their definitive habitat, the intestine, unharmed. It is even probable that certain of these enzymes are stimuli necessary before encystment can take place.

Certain species of intestinal protozoa, however, are not known to form spores, and their method of transmission is still in doubt. One notable case, however, that of *Trichomonas,* has recently been cleared up. Experiments have proved that the flagellate stage of the species, *Trichomonas muris,* that occurs in the rat, is able to pass unharmed through the mouth, esophagus, stomach and small intestine to the caecum, a distance of about 90 cm within half an hour and bring about an infection in the caecum. The human species, *Trichomonas hominis* (Fig. 1, C) therefore, which is known to be particularly resistant in the flagellate stage, probably brings about infections in new hosts by being ingested with the food.

Another large group of parasitic Protozoa are transmitted from host to host by inoculation by an insect or some other animal. This

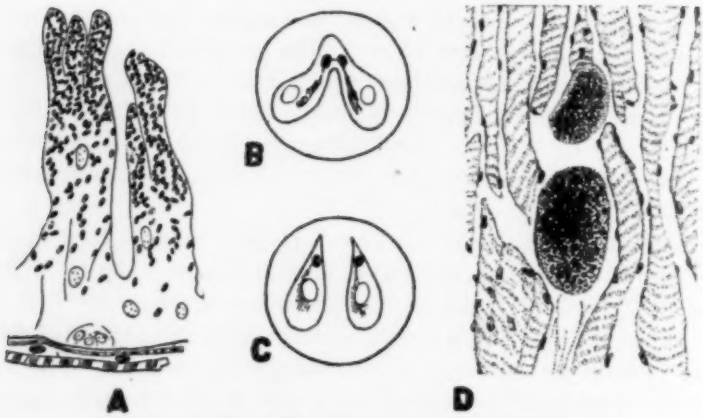


FIG. 6. PARASITIC PROTOZOA OF THE CLASS SPOROZOA

A. *Nosema apis* in wall of honeybee's stomach.
B. *Piroplasma canis* in a red blood cell of a dog.
C. *P. canis* after division.
D. Sarcosporidia in the muscle of man. (A, after White; B, C, after Nuttall; D, after Darling.)

is sometimes, but comparatively rarely, a mere mechanical transfer. Among the trypanosomes, most species ordinarily pass through part of their life-cycle in an invertebrate host, usually a fly, and a certain period must elapse between the ingestion of specimens by the fly and the development of infective stages within the fly, but rarely a fly, when feeding is interrupted, may immediately insert its proboscis into another animal and thus bring about an infection. In three species of trypanosomes this is the only known method of transmission. *Trypanosoma evansi,* the organism of surra in cattle and other domestic animals, and *Trypanosoma equinum,* the organism of mal-de-caderas in horses, are transferred mechanically by biting flies, and *Trypanosoma hippicum,* the organism of murrina in horses, is even distributed by a non-biting fly, the organism gaining entrance usually through harness wounds upon which the flies alight. It has recently been suggested that malarial organisms may be disseminated by mosquitoes by mechanical transfer, but there is no experimental proof of this as yet.

It is hopeless to attempt to describe all the different kinds of transmission by the inoculative method, but it is of interest to note that in most cases in which organisms are passed from one host to another without being subjected to an external environment no resistant spore stage is present. There may be spores, as in the malarial parasites, but these are not protected by a firm sporocyst.

The last type of infection of new hosts is often spoken of as

hereditary, inasmuch as the infective stage is transferred from the mother host to her offspring in the egg. The most notable instance of this sort was discovered by Pasteur in 1858, in the case of the microsporidian parasite, *Nosema bombycis* (Fig. 6, A), which causes silkworm-disease. Infection of silkworms with this protozoon may take place by the contaminative method, *i.e.*, by the ingestion by healthy worms of leaves soiled with feces containing spores, or by the hereditary method. In the latter case the ovaries of the infected moth are invaded by the parasites and the spores in the eggs remain dormant during embryonic development, becoming active in the caterpillar that hatches from the egg. Another notable example of hereditary transmission is that of the Texas fever parasite, *Piroplasma bigeminum* (Fig. 6, B, C), discovered by Smith and Kilborne in 1891, which infects the young of the cattle tick by way of the eggs. Hereditary transmission of malarial parasites was noted by Schaudinn but has not been confirmed; in fact, Mühlens has recently shown that the sporozoites of malaria penetrate almost every part of the body of the mosquito except the ovary.

### (7) Origin and Evolution of Parasitism

We really know nothing definite about the origin and evolution of parasitism, since no one has ever observed a free-living species become parasitic, but there are many known facts that are of value in any attempt to work out lines of descent. (1) In the first place the parasitic habit must be more recently evolved than the free-living habit, since free-living forms must have existed before the parasites could obtain hosts on which to live. (2) Ectoparasites probably evolved before entoparasites, because the change from a free-living existence to that of ectoparasitism does not appear to be so difficult as to that of entoparasitism. (3) Inasmuch as there are free-living as well as parasitic species in every large group of Protozoa, it is evident that the parasitic habit has arisen independently in each of these groups and may therefore be considered of rather common occurrence during the course of evolution. (4) Most parasites belong to groups that are more primitive than their hosts, *i.e.*, are lower in the scale of life. Protozoa can not be parasitized by animals more primitive than themselves, but may be parasitized by plant organisms. Protozoa, however, are often parasitized by others of their kind, *e.g.*, free-living hypotrichous ciliates may be parasitized by Suctoria (Fig. 4, A). (5) As pointed out above certain ectoparasites are not limited to one species of host; others have been observed on only one species; and certain species are confined to a definite part of the body of the host. These are sup-

posed to be stages in the evolution of ectoparasitism. A species that is able to migrate from one species of host to another is probably in a more primitive stage of parasitism than one that is limited to one host, and the latter condition has probably originated from the former. The third type of ectoparasite mentioned represents a still further specialization, the parasite being limited to a single organ of the host. (6) The relations between ectoparasitism and entoparasitism, and commensalism and symbiosis furnish much material for speculation. Do commensalism and symbiosis lead to parasitism? Many students believe that they do. For example, a species that takes its meals in a state of mutualism with another species might develop into a food robber and from this into an actual parasite. Or, symbiotic relations might become disturbed and instead of a more or less mutual association one member might develop gradually into a pathogenic parasite. (7) Entoparasites may be limited to one species of host or may pass through part of their life cycles in one host and part in another. How did entoparasitism arise and which of the two conditions mentioned is the more primitive? Entoparasitism may have arisen from ectoparasitism, from commensalism or from symbiosis. If an entoparasite is restricted to one host species it probably adopted the parasitic habit within this species and is therefore no older phylogenetically than its host. Any changes that have taken place in the parasite have probably proceeded coincident with changes in its host. When an entoparasite occurs in several host species, the parasite is probably older than its hosts, having adapted itself to hosts that evolved after it became a parasite. (8) Parasites that have intermediate hosts have probably evolved from parasites with only one host species. This condition may have arisen because of the ability of the parasite to adapt itself to changed conditions, at first simply tolerating the second host but later actually establishing itself within it. The entrances of exogenous stages of parasites into other animals is very widespread in nature, and plenty of opportunity exists for parasitism to arise. In such cases as the hemogregarine that alternates between the rat and the mite, change of host is probably related to the predaceous habit, the second host feeding on the first host and in time becoming necessary for the complete life-cycle of the organism.

### (8) Parasitism and the Geographical Distribution of Hosts

Finally, attention may be directed to the very interesting bearing of parasitism on the geographical distribution and genetic relationships of hosts. Von Jhering in 1902 was among the first to

discuss this problem in the case of parasitic worms. Zschokke in the following year compared in a similar way the distribution of tapeworms and marsupials, and the parasites of migratory fishes. Practically all parasites lend themselves to this method of attack. Kellogg (1905) has used it in his work on bird lice; Johnston has approached problems of evolution and zoogeography by the use of trematodes and cestodes, and Darling has studied the migrations of human races from data of hookworm distribution. The most important contribution to this subject resulting from the study of Protozoa is the recent work of Metcalf on the family Opalinidae (Fig. 1, D). This is too large a work to be disposed of in a few sentences, and those interested are therefore referred to the original report.

# THE PHYSICAL BASIS OF DISEASE

## I. CONGENITAL STRUCTURAL DEFECTS

By THE RESEARCH WORKER
STANFORD UNIVERSITY

IT was the first day out from Chicago. The group in the smoking compartment of the Overland Limited had already discussed many topics of current interest. The morning papers, received at Omaha, contained an account of the illness of a prominent government official. There was a garbled description of his symptoms, with a polysyllabic bulletin from attending physicians.

"Those doctors are four-flushing," said the salesman from New York. "They haven't the least idea what's the matter with H———. Medicine is the easiest confidence game now worked on an unsuspecting public."

"How can they expect to know?" said the man from Boston. "They haven't the least idea what disease really is. So long as they deny the existence of God, and putter around with microscopes and test-tubes, they will never know."

"I am not sure that all cures are to be attributed to Deity," said the manufacturer from Pittsburgh. "We rented a house in the Adirondacks this summer. The owner left a lot of books. I don't go in for high-brow stuff as a rule, but some of these books interested me. Do you know, the Mohammedans, when they are sick, bind texts from the Koran about the sore part. And it cures them. Real authentic cures, no fake stuff. And South Sea Islanders offer sacrifices to idols, and are really cured. If you attribute these cures to Deity, you will have to admit that these people are just as right about Deity as we are. It can't be Deity. It's the effect of mind on the body. Get the wrong idea in your head and it makes you sick. Replace it with the right idea and you get well. Mental therapy. The rest of medicine is pure bunk."

"And look at the way they quarrel among themselves," said the real estate man from Denver. "Christian Scientists, osteops, chiropractors, homeopaths, and the big allopathic bunch, calling each other liars and each claiming to have the only true light. You don't find such a thing in business. Take an automobile. It breaks down. Tow it to any garage, and they repair it in about the same way. Some mechanics are more efficient than others,

but they all go about it in the same way. One man doesn't pray over your flivver, another put hot compresses on your radiator, and a third massage your rear tire, as they do in medicine. Four-flushing is correct."

"Our Denver friend is right," said a quiet individual in the corner. "There is great confusion in practical medicine. But physicians aren't responsible for this."

"You're evidently a doctor," said the lawyer from Spokane.

"No. Merely a witness for the defense. I am a worker in a laboratory for medical research."

"In other words, a paid apostle for the allopathic bunch."

"Hardly that. It is true, research workers furnish physicians, no matter to what school they belong, with the facts they use or are at liberty to use in practice. But the average research worker takes more pleasure in exposing the mistakes and incompetence of physicians, no matter to what school they belong, than he does in discovering new facts. We claim to be impartial, competent critics of the methods of all schools."

"You claim physicians aren't responsible for the confusion?" asked the lawyer.

"The responsibility rests with the general public. Any garage that treated all broken cars by massaging the rear tire would go bankrupt. The public has sufficient knowledge of automobiles to realize the absurdity of such a method. At some time, some car owner may possibly have thawed out his radiator with a hot-water bottle. He might possibly be induced to write a testimonial endorsing the hot-water bottle method. But no business man would spend hundreds of thousands of dollars in manufacturing a special automobile hot-water bottle, in the expectation of selling thousands of these bottles to car owners for the treatment of all automobile troubles. The public, however, liberally supports hundreds of equally absurd medical devices."

"It's good business," said the manufacturer, "to give the public what it wants."

"I doubt if it's a good business policy in medicine. Hundreds of thousands of preventable deaths are caused by this policy. The economic loss is millions of dollars annually. This is eventually a drain on all legitimate business."

"There are adequate laws governing medical fakes," said the lawyer.

"The laws are neither intelligent, adequate nor well enforced. They never will be till the general public has sufficient knowledge of fundamental facts to intelligently judge medical claims."

"A four year medical course for every individual," said the lawyer. "Some program!"

"No. About six hours of the right kind of instruction."

"You mean to say you can make me a competent judge in that time?"

"There are certain fundamental facts that can be mastered in a few hours."

So it came about that the manufacturer, the lawyer and the man from Boston adjourned to the lawyer's compartment, where the research worker presented the facts he considered of most importance.

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"In the first place," said the research worker, "is there any one group of facts on which all physicians agree and which all practitioners must understand and use, no matter to what school of medicine they belong? There is such a group of facts in automobile repairing. Mechanics differ in methods, skill and efficiency in locating trouble and making repairs, but they all base their methods on an understanding of the physical nature of automobile trouble. A short circuit, a leaky valve, a cracked cylinder, deposits from inferior oil or gasoline. There is an equally fundamental group of facts in the human repair business."

"Suppose a physician doesn't accept these facts," said the lawyer.

"If a mechanic didn't believe in the existence of a short circuit, would you employ him to fix your car? His disbelief stamps him at once as incompetent. A short circuit is a fundamental mechanical fact. There are equally fundamental biological facts in human disease.

"Post-mortem examinations show that most diseases are caused by easily recognizable structural changes in the body. These are fundamental facts—not the subject of dispute. Elementary knowledge of the nature of these bodily changes in disease on the part of the general public would revolutionize practical medicine. I have selected facts of this kind to present to you.

"In presenting these facts I shall use the term 'disease' in a somewhat broader sense than generally employed. Your automobile may run smoothly and give full mileage, and yet be seriously defective. A cracked axle may markedly reduce your factor of safety. I shall use the term 'disease' to designate any alteration in the structure or function of any part of the human body, giving immediate symptoms, reducing efficiency, or reducing the factor of safety. These alterations all tend to shorten life. This is the usual technical meaning of the word 'disease'."

3

"As our first group of diseases, let us select the various structural defects that may exist in the human body at the time of birth. Such defects may be produced in various ways. During the developmental period each organ of the body is grown independently, from an initial bud. The growth of each bud is governed by hereditary factors which are not necessarily the same as the hereditary factors governing other buds. Each bud is influenced by environmental factors, accelerating, retarding or modifying its growth. Many buds are located at a distance from their final places in the body, so that they must migrate during the developmental period.

"Fully 20 per cent. of all human embryos are discarded by nature before reaching full-term development. In many cases this is due to the death of the embryo from structural defects. At birth a considerable percentage of human young are found to be so grossly deformed as to be classed as monstrosities. Fifteen per cent. of all children die during the first month after birth. Autopsies show that half of these deaths are due to serious structural defects. Minor structural defects are probably present in most of us.

"These structural defects are of several types. A common type is congenital dwarfism of important organs or parts. You are familiar with this defect in external parts of the body, as shown by unusually small individuals, or individuals with an undersized arm, leg or head. Dwarfism is even more common in internal organs. A kidney the size of a pea is not uncommon; a lung may be entirely absent, or represented only by a bud the size of an olive; the stomach may be so rudimentary that for all practical purposes the esophagus joins directly on to the intestine. Individuals with such defects often reach adult life with no serious symptoms. There is a very generous factor of safety in the body."

"You use the term 'factor of safety'," said the manufacturer, "as though you could actually measure such a thing."

"Many of the factors of safety in the human body are subject to as accurate measurement as that used in most engineering work. I don't refer merely to such structures as bones and tendons, whose breaking strength can be determined in the same way one determines that of wood or steel; but to such organs as the heart, liver, lungs and kidneys. Take the kidneys, for example. Half, two thirds, three quarters, or the entire kidney tissue can be removed surgically from animals, and the effects on excretion determined. It is not till two thirds of the kidney tissue is thus removed that the remaining portion becomes inadequate for ordinary excretion.

This gives a factor of safety or reserve power in the kidney of three to one above ordinary needs.

"Dwarfism in certain organs, however, may give serious symptoms. Underdevelopment of the brain or of certain brain areas, for example, shows itself in reduced mental capacity and altered bodily control. Dwarfism of the thyroid gland produces mental inferiority."

"I have one criticism of medical men," said the lawyer. "They expect us to accept as gospel truth any statement they make, though in reality the statement may represent only a theory, often a damned poor theory on their part. That the little piece of meat in the neck you call the thyroid is responsible for mental inferiority strikes me as a statement of that kind."

"I am glad you mention this. I probably did not make it clear just what type of facts I am presenting. Medieval literature contains numerous descriptions of congenital idiots, cretins or semi-cretins—undersized individuals with infantile intellects. In medieval times a cretin was regarded as possessed of the devil, and was treated by religious methods. No cure by these methods, however, is recorded in all literature. As we shall see later, cretinism is not a type of disease that can successfully be treated by religio-therapy."

"Then you do admit there's something in religious treatment," said the lawyer.

"I fear I should be misunderstood if I admitted or denied it at this stage of our discussion.

"With the introduction of modern methods, autopsies were made on cretins. It was found that no matter what changes were present in other organs of the body, all cretins had one thing in common—abnormalities in the size or structure of the thyroid gland. Physicians therefore commenced to wonder whether or not there was a connection between an abnormal thyroid and cretinism. It was of course possible that the thyroid abnormality was a result of cretinism, or an unimportant accompaniment. There were physicians so bold, however, as to put forward the theory that the observed change in the thyroid gland was the cause of cretinism. This was of course pure theory, merely suggested by the statistical data.

"Assuming for the sake of argument that thyroid abnormality causes cretinism, the question arose as to how this was brought about. About the only way one can think of the thyroid gland as affecting mentality would be either (1) by destroying certain substances in the circulating blood that might injure the brain, or (2) by supplying the brain with necessary food substances or stimu-

lants. Assuming that the effect was by the latter method, physicians wondered whether or not the necessary brain foods or brain stimulants could be obtained from thyroid glands of lower animals. Physicians therefore administered extracts of thyroid glands of sheep to numerous cretins. A miracle was performed. The undersized, idiotic child often gained weight and mental vigor, and became practically a normal child within a few months.

"Study of thyroid function was now taken over by laboratory workers. It was found that conditions approaching cretinism could be produced on laboratory animals by the surgical removal of part of the thyroid gland. Chemists isolated an iodin compound from thyroid glands with which cretinism could be successfully treated. The relationship between thyroid insufficiency and cretinism is a proved biological fact. Every fact I shall present rests on an equally firm scientific basis."

4

"As our second type of structural defects, let us select the opposite condition—defects due to giantism or to duplication of important organs or parts. Giantism or duplication may affect the body as a whole, giving the excessively large individuals or double individuals occasionally born to normal parents; or it may affect any external part, giving rise to abnormally large or duplicated heads, hands or feet. Giantism or duplication is common in internal organs. A kidney, so large as to almost completely fill the abdomen, a second spleen, a third lung, are not at all rare at birth."

"I should think an unusually large kidney would be of advantage," said the manufacturer.

"The functions of the various organs are so evenly balanced that excessive growth or duplication of one part often leads to serious symptoms. Take the thyroid gland. This gland is occasionally congenitally enlarged or duplicated. We would expect one effect of this thyroid overgrowth would be the manufacture of excessive amounts of thyroid brain foods or brain stimulants. Extract from sheep thyroid administered in excessive doses or in too frequent doses produces marked intoxication, shown by palpitation of the heart, nervousness, insomnia, trembling and vomiting. These are the symptoms that are constantly or intermittently present in many individuals with congenitally enlarged or duplicated thyroid glands."

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"As our third type of structural defects, let us take deformities or distortions of important organs or parts, not necessarily asso-

ciated with abnormalities in size. Such deformities may be produced in several ways. One group, for example, is caused by a failure of union or fusion of early embryonic buds which normally fuse to form the adult organ or part. You are familiar with such deformities of the face. The early embryonic face, as you know, is represented by a series of buds which later unite and fuse to form the nose, lips and jaws. Failure to unite leaves open clefts or fissures at the time of birth, giving the various forms of hare-lip, cleft palate and unclosed passages to the trachea. Similarly, the brain and spinal cord are represented in early embryonic life as an unclosed depression or fold along the back. Imperfect fusion of the sides of this depression may leave various parts of the brain or spinal cord uncovered at the time of birth. Imperfect fusion of the abdominal walls may leave openings into the abdominal cavity.

"Incomplete fusion of embryonic structures also takes place in internal organs. The early embryonic heart, for example, is merely a U-shaped blood vessel. This gradually twists upon itself and fuses to form the later embryonic heart. Ingrowing buds in this twisted tube unite and fuse to form the partitions separating the heart chambers. These buds often fail to unite, leaving abnormal openings between the heart chambers."

"Such conditions must be rare," said the manufacturer.

"They are surprisingly common. Nearly 15 per cent. of all autopsies in certain hospitals show unclosed openings in the partitions between the right and left sides of the heart. The seriousness of this defect is at once evident. An unclosed opening in the partition between the two ventricles, for example, may allow blood to pass directly from the right side of the heart to the left side without first passing through the lungs. Unaerated or venous blood may be thus pumped out into the aorta to supply the needs of the body.

"Deformities or distortions of organs may also be produced by an abnormal union and fusion of structures which normally remain separate. Two or more fingers or toes may be grown together; the two eyes may be fused to form a single eye in the center of the forehead; the mouth opening may be absent. One of the most important fusions in internal organs is the absence of the opening between the stomach and intestines. Portions of the intestine may also be grown together to form solid cords. The external opening of the intestine may be absent. A fairly common example of fusion is found in the kidneys. The two embryonic kidneys occasionally unite to form a large single distorted organ."

"A single double-sized kidney wouldn't be a disadvantage," said the manufacturer.

"Not so far as the usual functions of the kidney are concerned. It is a disadvantage, however, in reducing one of the factors of safety in the body. One of our factors of safety is a duplication of organs or parts. Tuberculosis may destroy one kidney, for example, leaving the other kidney uninjured and capable of performing all necessary functions. Tuberculosis of a fused kidney, however, would tend to destroy the entire excreting mechanism."

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"Probably the most important group of structural defects are defects due to inferior structural material. The thyroid gland, for example, often shows this defect. Under the microscope the thyroid gland is seen to be composed of definite groups of special thyroid cells held in place by blood vessels and supporting tissues. A thyroid gland of normal size may be found microscopically to contain few, if any, thyroid cells. Its main bulk may be made up of an excessive amount of supporting tissue or of dilated blood vessels. Or, in place of the normal thyroid cells, there may be immature cells, or cells markedly shrunken, atypical or senile.

"The manufacture of the necessary brain foods or brain stimulants by the thyroid gland is carried out in the special thyroid cells. The other structures serve merely to mechanically support and nourish these cells. If the special cells are reduced in number, or are immature, or degenerate, the capacity of the gland to manufacture the necessary brain foods or brain stimulants is reduced. It is found, for example, that a certain percentage of cretins have thyroid glands of normal or even of increased size. Microscopically, however, these glands are always deficient in normal thyroid cells.

"Not all the inferiorities in structural material are so easily seen as this. Altered chemical composition, reduced growth potentiality, tendency to premature senility, may not show themselves microscopically. We have abundant evidence, however, that defects of this kind may be present at birth in the building materials of any organ or part of the body."

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"There are several minor types of structural defects we might consider. Among these are the curious misplacement of important organs, such as a liver or stomach located in the thorax, or a kidney deep in the pelvic cavity. Then there is the weird production of wholly abnormal structures in various parts of the body, such as a rounded mass containing bone, teeth and hair in the abdomen; or distorted sexual tissues growing from the roof of the mouth."

"It's sacrilege!" said the man from Boston. "The Supreme Power can't make such mistakes."

"Whether or not one considers it sacrilegious depends upon one's conception of the forces controlling embryonic development. The embryo, as you know, does not receive a single nerve or blood vessel from the mother at any stage of its development. It grows as an independent parasite, sucking up nourishment from the maternal tissue juices, in about the same way a plant sucks up nourishment from the ground. There are certain biologists so bold as to claim that the only forces governing embryonic growth are the ordinary physical and chemical forces of nature. Others believe that supernatural forces control or guide the entire processes of embryonic development. Still others conceive a spirit control to enter during a late stage of development, at the time of 'quickening.' Formal biological science has no quarrel with men who take any of these views. The subject is beyond the reach of experimental or observational science. It belongs to the realm of speculation, theory and faith."

"We are pulling into North Platte," said the manufacturer. "Let's get out and stretch our legs."

# RESEARCH; THE MOTHER OF INDUSTRY[1]

By ARTHUR D. LITTLE

We are living in an age in which new impressions so crowd upon us that the miracle of yesterday becomes the commonplace of to-day. We fail to appreciate how rapidly our environment is changing, or how profoundly it has changed. In spite of the premature grayness of my residuary hair, you will, I am sure, be polite enough to agree that I am still a young man. I am, in fact, in the position of the little negro girl, who was asked how old she was. She said, "If you asks me how old I is, I'se five, but if you asks me how much fun I'se had, I'se most a hundred." When I review the industrial developments that have taken place within my recollection, I feel like the grandfather of Methuselah.

In "Mis' Nelly of New Orleans" Mrs. Fiske says, "I hate old friends, they always refer to 'that delightful Friday afternoon at the Centennial.'" You will forgive me for recalling that at the Centennial I saw, as a small boy, the first telephone and the first commercial arc light. May I also record that for ten successive days I ate Philadelphia ice cream. In 1884 I was trying to make 10 tons a day of sulphite pulp in the first mill on the continent. To-day we make 7,000 tons. When I opened a laboratory in Boston the street cars were drawn by horses, and I remember the clang of the first electric cars on Boylston Street and the consternation they caused among their equine competitors. From my window on Beacon Street two thousand bicycles an hour could be counted, where now more automobiles pass. I have seen the fish-tail burner supplanted by the Welsbach mantle and the incandescent electric lamp develop from carbon to tungsten filaments through to the white light of argon-filled bulbs. I remember the thrill with which I first saw an aeroplane sweep at dusk across the disc of the rising full moon and soar to invisibility above. Since then men have crossed the Atlantic in a single day and flown a mile in 13 seconds. Within a month the Shenandoah, filled with helium, has sailed majestically over the basin which faces my office window. That evening the Boston *Transcript* printed a description of the flight sent to its office by wireless from an aeroplane above the airship. I went with the crowd to hear Barnum's talking machine, cumbersome as a church organ, make guttural noises that bore an imagined

[1] Paper presented before a meeting of the Division of Engineering, National Research Council, University Club, New York, December 7, 1923.

resemblance to human speech, and later, in the Old South Church, heard Edison's phonograph, no bigger than a typewriter, reproduce a cornet solo by the passage of a needle over tin foil. Where the zoetrope excited the wonder of the children of my generation, the moving picture now bores thousands and entertains tens of millions. I still preserve the quill pen with which I often saw my grandfather write, and during my own first years in business all our letters were in longhand and copied in a press.

I well remember the incredulity which the announcement of the X-rays excited in some lay quarters, and the whole marvelous story of radium, which has led to altogether new conceptions of the structure of matter, is, of course, a tale of yesterday. It seems but a few short years since Hertz announced the discovery of long ethereal waves, which could be refracted and focussed by great prisms and lenses of pitch; yet during those years there has developed the whole wonderful system of wireless telegraphy and radio-telephony.

When I began the study of chemistry we were taught that there were certain permanent gases. They were called permanent because they could not be liquefied, but, almost before I had learned the lesson, Pictet and Cailletet had liquefied oxygen. There are now no permanent gases, and liquid air has become a commonplace of the laboratory and the raw material for great industries.

I was also taught that atmospheric air contained only oxygen, nitrogen, aqueous vapor and a small proportion of carbon dioxide. As even Mr. Bryan would admit that the human race has been immersed in air for at least six thousand years and might reasonably be assumed to know all there was to know about it, I accepted the instruction at its face value. Lord Rayleigh and Sir William Ramsay were less credulous and by the most brilliant, patient and refined research demonstrated the existence in the air we breathe of five hitherto unknown gases: argon, helium, neon, krypton and xenon. Even their names carry interest and suggestion. Argon, the lazy one, because it forms no compounds; helium, because the spectroscope had revealed its existence in the sun before its discovery on earth; neon, the new one; krypton, the hidden one; and xenon, the stranger. But already the lazy one has been put to work in incandescent lamp bulbs; helium, with nearly the lifting power of hydrogen and non-inflammable, has become the key to the safer navigation of the air by dirigibles; while neon tubes flash advertisements in shop windows and assist chauffeurs to locate engine troubles.

In 1898, Sir William Crookes, having in mind the inadequacy of the supply of nitrogenous fertilizers for the agricultural needs of our expanding population, and speaking as president of the

British Association for the Advancement of Science, said, "England, and all civilized nations, stand in deadly peril of not having enough to eat." That peril is now removed by the effective and spectacular processes, developed by chemists, for the production of such fertilizers by the fixation of nitrogen from atmospheric air.

My study of chemistry began with Eliot and Storer's Manual. Its copious index contains no reference either to catalysis or colloids. To-day catalysis has a copious literature of its own and is recognized as the determining factor in hundreds of reactions, on which are based new industrial methods for the production of such important and diverse materials as edible fats, ammonia, sulphuric acid, synthetic dyes and whole series of hydrocarbon derivatives. Colloid chemistry has become no less inclusive. It permeates such industries as tanning, artificial silk, rubber, smokeless powder, celluloid, photography and soap. It solves the problems of the makers of ceramic wares, shaving creams and shoe blacking.

The decade beginning with 1890 was notable for great industrial developments based upon research. In that year Hall brought out the aluminum process; in 1891 Acheson began the manufacture of carborundum and made available abrasives of a new order of efficiency; in 1892 Willson established the basis for the carbide, acetylene and cyanamid industries by his process for calcium carbide; in 1893 the Diesel engine was invented, Cross and Bevan communicated to me their discovery of viscose from which last year one American company made 22,000,000 pounds of artificial silk, and I demonstrated the Schultz processes for chrome tanning which have revolutionized the leather industry; in 1894 the automobile was developed; at about this time I was engaged in the investigation of the new electrolytic processes of Le Sueur and others for the manufacture of bleaching powder and alkali and was producing, by laboratory methods, cellulose acetate, the substance by which, during the world war, the wings of airplanes were protected; in 1895 Röntgen announced the X-rays; in 1896 Becquerel discovered radio-activity; in 1897 synthetic indigo, the product of German technical skill and financial courage, was placed upon the market and established still more firmly German control of the dyestuff markets of the world; in 1897 also Marconi sent a wireless message across Bristol Channel, while 1898 will be forever memorable for the discovery of radium.

As business men, you are accustomed to forecast tendencies by the trend of plotted curves. Let me assure you that the trend of the research curve is steeply upward. Research, which has paid these heavy dividends and countless others in one decade, needs only your recognition and support to enable it to pay still more heavily in the future. The vein is constantly widening, and the instru-

ments of research grow steadily more effective. Equally is it true that the means of reducing research results to practice are to-day incomparably better than they ever were before.

I would apologize for having given to this fragmentary and totally inadequate review so personal a tone were I not anxious to bring home to you the fact that all these great developments, so far-reaching in their influence upon industry, our mental outlook and our entire social structure, have taken place within the easy recollection of a man still on the job. Perhaps you recognized and turned to profit some of the opportunities that these developments afforded. Whether you did or not, it is worth your while to bear in mind that another procession is forming around the corner.

Three fundamental factors are involved in industry: capital, labor and the creative mind. The creative mind may function along the line of organization and management, or it may function along the line of research. In any progressive civilization industry is constantly pushing its outposts forward into the new territory wrested from the unknown by its advance guard, science. Now science is merely information, so classified and organized as to be used effectively and at once, and information, to quote General Phil Sheridan, is "the great essential of success." Advance information of the result of the Battle of Waterloo consolidated the Rothschild fortune. It is advance information, which may be of equal potential value, that research offers you.

Research to-day is extending the boundaries of every field of human activity and thought. It is to-day, more effectively than ever, directing industrial expansion into new channels and new territories. We are, for example, about to witness revolutionary changes in the preparation and use of fuel. Powdered coal has already established itself in engineering practice. Much progress has been made in low-temperature carbonization with higher recoveries of chemical values and the production of artificial anthracite. The conversion of coal to liquid hydrocarbons through hydrogenation has been demonstrated on the commercial scale in Germany, though the figures on the balance sheet are doubtless still in red. The gas industry is destined to a great expansion, which will involve radically new methods. The industrial use of gas has scarcely begun, yet in Baltimore, within the last six years, more gas has been consumed than during the preceding century. Systems for the complete gasification of coal have been developed, and there are serious proposals for great gas works at the mines and the distribution of industrial gas through high-pressure mains.

Steam pressures in central stations have reached 500 pounds, and pressures of 1,200 and even 1,500 pounds are cautiously being

tried. They present problems in the behavior and strength of steel at high temperatures in contact with water and gases that can only be solved by intensive research. The gas turbine presents other problems, which seem to be nearing a solution, but here, again, is more research required.

Decades of research have brought us to the point where we may soon expect oxygen, the supporter of combustion, to be as cheap by the ton as coal. That implies an impending revision of blast-furnace practice and of many operations in general metallurgy. It presents the possibility of the continuous gas producer and should raise the quality and heating power of industrial gas. It calls for new refractories.

Petroleum is about to be raised to a new and higher plane of usefulness and value, where it will serve as the starting point for the synthesis of whole series of organic compounds.

Biological chemistry is contributing new fermentation processes, which yield butyl and amyl alcohols, acetone, glycerine and fats, and in its alliance with medicine is conquering some of the most terrible scourges of the human race.

In 1922 Bohr published "The Theory of Spectra and Atomic Constitution." That, I submit, is seemingly far removed from industry and practical affairs. But Bohr's theory indicated that an unknown element should exist in zirconium-bearing minerals. In 1923 Coster and Hevesy, by means of X-ray analysis, found the element as predicted. It is named hafnium, in honor of Borh's city, Copenhagen. That you may the better appreciate the potentialities of this discovery let me add that hafnium is estimated to represent 1/100,000th of the earth's crust and to be, therefore, more plentiful than lead, tin and many other metals of commerce.

The French chemist, Dumas, writing to Pasteur concerning Lavoisier, the father of chemistry, said:

> The art of experimentation leads from the first to the last link of the chain, without hesitation and without a blank, making successive use of Reason, which suggests an alternative, and of Experience, which decides on it, until, starting from a faint glimmer, the full blaze of light is reached.

Our prosperity in the past has been largely based on cheap land and superabundant raw materials. To-day our civilization has developed such complexity that we can not hope to maintain our position except through the assistance which only science can afford. The laboratory has become a prime mover for the machinery of civilization, and the evidence that has been placed before you justifies the claim that there is a direct obligation upon industry to support research with the generosity of an enlightened self-interest, for research is the mother of industry.

# THE RADIATION OF LIGHT[1]

By Professor HENDRIK ANTOON LORENTZ

LEIDEN UNIVERSITY

BEFORE beginning my lecture I want to say in the first place that I feel it as a great honor to have been invited by this institution that has been made famous all over the world by the scientific men who worked in it, and in which, above all, there is so much that reminds us of Michael Faraday, the greatest discoverer in physical science perhaps who ever lived. Allow me in the second place to pay a tribute to the memory of Sir James Dewar, whose loss all physicists deeply deplore, thinking with great admiration of the talent with which he opened new paths of research. He has worthily continued the history of the Royal Institution, which forms an important chapter in the history of science itself.

One of the lessons which this history of science teaches us is surely this, that we must not too soon be satisfied with what we have achieved. The way of scientific progress is not a straight one which we can steadfastly pursue. We are continually seeking our course, now trying one path and then another, many times groping in the dark, and sometimes even retracing our steps. So it may happen that ideas which we thought could be abandoned once for all have again to be taken up and come to new life.

These remarks are well illustrated by the way in which at different times physicists have represented to themselves the way in which light is produced and radiated. You all know the two contending views, the emission theory or the corpuscular theory of light, developed by Newton, and the undulatory theory proposed by Huygens, perfected afterwards by Young and Fresnel, and newly shaped as the electromagnetic theory of light by Clerk Maxwell. I should now like to point out to you how these two theories, however widely different their principles may be, were interwoven in Newton's mind, and how it is well possible that they will be interwoven again in the physics of the future.

When one reads Newton's "Optics," one can not doubt that, when he speaks of a ray of light, he always thinks of a stream of small corpuscles emitted by a luminous body and moving along in straight lines, so long as they are not acted upon by some deflecting force. The phenomenon of diffraction, as we call it now, that had been discovered by Grimaldi and which Newton carefully examined

[1] Lecture before the Royal Institution of Great Britain, June 1, 1923.

experimentally, I mean the phenomenon that the shadow of a thin wire, for instance, is wider than it would be in the case of undisturbed rectilinear propagation, was attributed by Newton to certain repulsive forces with which the wire acts upon the rays of light when they pass along its surface at a very small distance.

The reflection and the refraction of light were likewise considered as due to forces which act upon the corpuscles of a ray when they come near the surface of separation of two media, like air and glass or water. Newton expressly states that the corpuscles must not be conceived to be reflected by the *individual* molecules of the body on which they impinge. If we could see the molecules, we should find the surface to be very rough, and it would be clear that their individual actions can hardly lead to a regular specular reflection. For this reason Newton supposes that the corpuscles of light are acted upon, not by the molecules separately, but by parts of the bodies containing a great number of them. This does not prevent us from supposing the actions in question to be appreciable at very small distances only. If they were sensible up to one ten thousandth of a millimeter, for instance, and if you had a corpuscle situated at half that distance from a polished plate of glass, then, since the structure of the glass is very fine grained with respect to the distance in question, the corpuscle would be acted upon by an immense number of molecules, and the discontinuities would not make themselves felt, so that it would be as if we had a perfectly smooth surface.

The forces of which I am speaking are comparable to those that were introduced much later by Laplace in the theory of capillarity. A corpuscle in the interior of a body will experience equal forces in all directions, so that there will be no resulting force and the particle continues its way with a constant velocity. It is only in a very thin layer, extending on both sides of the surface of separation, that there will be a resulting force, due to the unequal attractions, or perhaps repulsions, which the two media exert on the corpuscle. For reasons of symmetry the resulting force is perpendicular to the surface of separation, and therefore, whether the corpuscle be reflected into the first medium or allowed to continue its way in the second, the component of the velocity in the direction of the surface will remain unchanged. From this you can easily deduce the law of reflection. As to that of refraction, a simple diagram (Fig. 1) shows that, if the velocity along the surface A B is the same before and after the refraction, the sines of the angles which the ray makes with the normal N N, the angle of incidence $i$ and angle of refraction $r$, will be inversely proportional to the velocities, say $v_1$ and $v_2$ with which the corpuscles move on the two sides of the surface, indeed, since the component of the velocity along the surface is $v_1$

sin $i$ on one side, and $v_2 \sin r$ on the other, its constancy requires that

$$\sin i : \sin r = v_2 : v_1.$$

We shall therefore have found the well-known law of refraction, *viz.*, the constancy of the ratio between the two sines, if we suppose $v_1$ and $v_2$ to have definite values, whatever be the angle of incidence. Now, if the first medium is air, or rather the ether, we shall suppose $v_1$ to have a definite value, at least for rays of a particular color, on account of the way in which light is emitted. Once taking for

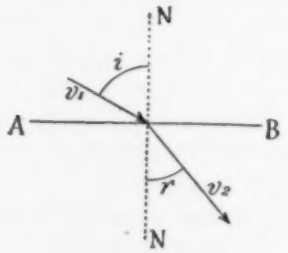



FIG. 1

granted this constancy of $v_1$, we can assure ourselves of that of $v_2$ by taking into account that the passage of a corpuscle from the interior of the first medium to the interior of the second will be accompanied by a definite change in the value of the potential energy, this value being in each medium the same for all positions of the corpuscle and whatever be its motion. By the law of conservation of energy the change in the kinetic energy of the corpuscle must be equal and opposite to that of the potential energy; thus, the difference $v_1^2 - v_2^2$ must be the same in all cases, and the constancy of $v_2$ follows from that of $v_1$.

I shall dwell no longer upon the further development of the corpuscular theory, but I must now point out to you how Newton also had the notion of vibrations, and even of waves, that are propagated in a medium. He was led to this by his experiments on the colors of thin plates, which we now attribute to interference, and which he examined very carefully for the case of the thin layer of air contained between a plane surface of glass and a surface that is slightly convex. Here we have the phenomenon generally known as Newton's rings. Suppose the light to be homogeneous and the incidence to be normal. Then, both in the reflected and in the transmitted light, you will see a number of alternating bright and dark rings, the dark rings in the transmitted light having the same diameters as the bright ones in the reflected light. This means of course, what is quite natural, that, at a thickness of the layer for which a great part of the light is reflected, only a small part is transmitted, and conversely.

The experiment shows that, of all the rays that enter at the front surface of the layer, some will be reflected at the back surface and others not, and that this depends on the thickness of the layer, the distance between the two surfaces. Further, that there is a certain periodicity in this. Now, since two rays, one of which is reflected at the back surface and the other not, must obviously be more or less different, Newton supposes that, after having passed the first surface, a ray or a corpuscle is in alternating states, *fits*, as he calls them, *of easy reflection and easy transmission*. But I think I had better give you this in his own words:

> What kind of action or disposition this is; whether it consists in a circulating or a vibrating motion of the ray, or of the medium, or something else, I do not here enquire. Those that are averse from assenting to any new discoveries, but such as they can explain by an hypothesis, may for the present suppose, that as stones by falling upon water put the water into an undulating motion, and all bodies by percussion excite vibrations in the air; so the rays of light, by impinging on any refracting or reflecting surface, excite vibrations in the refracting or reflecting medium or substance, and by exciting them agitate the solid parts, of the refracting or reflecting body, and by agitating them cause the body to grow warm or hot; that the vibrations thus excited are propagated in the refracting or reflecting medium or substance, much after the manner that vibrations are propagated in the air for causing sound, and move faster than the rays so as to overtake them; and that when any ray is in that part of the vibration which conspires with its motion, it easily breaks through a refracting surface, but when it is in the contrary part of the vibration which impedes its motion, it is easily reflected; and, by consequence, that every ray is successively disposed to be easily reflected, or easily transmitted, by every vibration which overtakes it. But whether this hypothesis be true or false I do not here consider. I content myself with the bare discovery, that the rays of light are by some cause or other alternately disposed to be reflected or refracted for many vicissitudes.

Let me add that, in order to account for the fact that light falling on a surface of glass is partially reflected and partially transmitted, Newton assumed that fits of easy transmission and easy reflection exist already in the incident rays before they reach the surface. He supposed *these* fits to have been impressed on the rays already in the act of emission itself; in fact he went so far as to imagine something like vibrations to go on in the source of light. Query VIII near the end of the book begins with the words: "Do not all fix'd bodies, when heated beyond a certain degree, emit light and shine; and is not this Emission perform'd by the vibrating motions of their parts?"

So there was much of vibratory or undulatory theory in Newton's ideas, though he seems never to have thought, as Huygens did, of the ray itself consisting in a propagation of waves. In Query XVII he again compares the ray of light falling on the surface of some substance to a stone thrown into stagnant water.

As you all know, the conclusion that the sines of the angles of incidence and refraction would be *inversely* proportional to the velocities of propagation became fatal to the corpuscular theory. The undulatory theory required that the two sines be *directly* proportional to the velocities of propagation, and when, about a century ago, the velocity of light in water could be measured, the result was in full agreement with the wave theory. I can briefly state the facts by saying that the index of refraction of water is about 4/3. The velocity of light in water ought therefore to be 3/4 of that in air according to the undulatory theory, and so it was found to be, but the corpuscular theory requires that it should be greater than the velocity in air, *viz.*, 4/3 times that velocity.

There now came a period during which the wave theory reigned supreme, until in these last ten or twenty years physicists were led to ideas, not exactly the same as Newton's but still more or less similar to the notions of the corpuscular theory.

The beginning of it was that, on the basis of the electromagnetic theory, a beam of light was recognized to possess a certain momentum, comparable to that of a moving ball. For the ball the momentum is given by the product $m\ v$ of the mass and the velocity, and when we attribute to the beam of light a certain momentum, say an amount Q of it, we simply mean to say that the beam has the same power of setting bodies in motion as a body would have, for which the product $m\ v$ has just that value Q.

The existence of momentum in a beam of light is shown by the pressure of radiation that was predicted by Clerk Maxwell, and observed and measured first by Lebedew and afterwards by E. F. Nichols and Hull. Let us consider this question for the case of a beam of light falling normally on a perfectly reflecting mirror, and let us compare the explanation by the undulatory theory, and the explanation that could be given by a follower of Newton, if there were one in these times. For the sake of simplicity I shall suppose that we hold the mirror in position by applying to it a certain force. If we can calculate that force we shall also know the pressure on the mirror, to which it is equal.

In the experiments the pressure has been compared to the energy which, in the beam of light, falls on the mirror in unit of time, the two quantities being proportional to each other. Now, according to both theories, the momentum which falls on the mirror has its direction reversed, and the ratio in question will be equal to that of twice the momentum of the light that reaches the surface during a certain time, to the energy of that same light. In the corpuscular theory this would be the ratio of $2\ m\ v$ to $\frac{1}{2}\ m\ v^2$, or $4/v$; thus, when $c$ is the speed of light, $4/c$. On the undulatory theory the ratio

between the momentum and the energy of a beam is that of 1 to $c$, by which the result becomes $2/c$. You see that, for a beam of a given intensity, the pressure would be different in the two theories, in the undulatory theory half only of what it would be on the other view, so that here again we have a crucial experiment. The measurements have clearly decided in favor of the wave theory.

Our neo-Newtonian would have to own himself defeated by this, if he had been taught classical mechanics only, and had never heard of the changes that have been brought about by the theory of relativity. If he has studied this latter theory there is an escape for him; indeed, he can point out triumphantly that the values which relativity assigns to the momentum and the energy of any moving system are such that our last result $2/c$ holds in all cases. Only, this appeal to relativity would imply that the corpuscles become widely different from what they were originally thought to be. According to relativity dynamics a thing moving with the speed of light and having a finite mass, however small it may be, would have an infinite momentum and an infinite energy. Therefore, since the pressure has a finite magnitude, a corpuscle must be something with no mass $m$ at all, but which, nevertheless, when moving with the velocity $c$, has a finite energy and momentum. By these assumptions the corpuscles become much like the so-called light quanta of modern theory, about which I should now like to say some words.

The word "quanta" is used by physicists in two different senses. In some cases we mean by it no more than definite amounts of energy of radiation, whose magnitude is proportional to the frequency $n$, or number of vibrations in unit of time, so that it can be represented by $h\ n$, where $h$ is a constant. In this form the idea originated with Planck, who used it in the problems of heat radiation, and after whom the constant $h$ is generally called. In Bohr's theory of spectral lines these minute amounts of energy play a fundamental and most important part; one of his assumptions being that light is not emitted in quantities of any magnitude, but in a greater or smaller number of full quanta that are radiated successively, one at a time.

It ought to be remarked that in this form the notion of quanta has nothing that is very startling or mysterious. If a tuning fork is made to vibrate by taps of a definite intensity, the fork being allowed to lose all its energy before it receives a new blow, we shall have emission of "sound quanta." We can imagine without difficulty that similarly in a source of light the energy is measured out in small but finite portions of a fixed magnitude.

However, this does not always suffice. There are phenomena from which, if we had to judge by them solely, we should certainly

infer that the energy of a quantum not only has a definite amount, *but also remains confined to a very small space.* In this way one has been led to the idea of "concentrated quanta," which may well be said to be Newton's corpuscles in a modernized form.

The phenomena to which I alluded are those of photoelectricity. When light of a suitable frequency is let fall on a plate of a properly chosen substance, electrons are set free, and it has been found that the energy of each of these electrons is equal to the quantum for the light which we use. This can be easily understood if the quanta are confined to small spaces, so that the electron can catch at once a whole quantum, whereas, when a quantum is spread out over a considerable extent, it is very difficult to see how an electron is to get hold of it. So the phenomena of photoelectricity seem to speak in favor of some corpuscular theory.

Let us, in order to make this clearer, suppose that the sensitive plate is first placed at a small distance from the source of light, and is then removed to a distance a hundred times as great, so that the intensity of the light or the total energy that falls on the plate in a certain time becomes 10,000 times less. Observation shows that the number of electrons liberated from the plate also becomes 10,000 times less, but that they are ejected with exactly the same velocity as before. This would be very natural if we could adopt some form of corpuscular theory, either the old or the modernized one. Then it would be clear that the number of corpuscles striking the plate has diminished in the ratio I mentioned, but that each individual corpuscle can do just what it did at the smaller distance, for the velocity has not been altered, and the corpuscle or the concentrated quantum has lost none of its properties.

On the contrary, when there are no concentrations, when, in spreading out, the energy becomes more and more dilute, we should expect that, at a certain distance, the light becomes too feeble ever to liberate an electron.

So it would seem that we really want concentrated quanta. But now, having recognized this, we have to face a very serious difficulty, a difficulty that hangs as a heavy cloud over this part of physics. Indeed, the existence of narrowly limited disturbances of equilibrium is absolutely irreconcilable with the principles of the undulatory theory as they are embodied, for instance, in Maxwell's equations of the electromagnetic field. According to these equations a disturbance of the state of the ether can never remain confined within a space of constant magnitude; around each point that is reached by the disturbance there is a propagation in all directions, and so there is always the tendency to a lateral expansion that becomes manifest in the phenomena of diffraction. It is true that,

when our openings are wide in comparison with the wave-length, we may have beams of light that are rather sharply defined over a certain length, but if we go far enough along the beam we shall ultimately notice an unlimited expansion. When, for instance, parallel rays are made to pass through an opening of one centimeter in diameter, we shall observe an illuminated circle of the same magnitude with a rather sharp border on a screen at a distance of some meters, but if the screen is removed to a distance of 100 kilometers, there will be a badly defined patch of light extending over something like half a meter. Or, again, take the case of a disturbance initially confined within a spherical space a centimeter in diameter. At some later instant it will be found in a shell of this thickness, bounded by two concentric spheres which both expand with the speed of light. By properly choosing the distribution of the disturbance in the initial sphere, you have it in your power to produce different distributions in the expanding shell, but you can never prevent the disturbance from ultimately occupying a very considerable part of the spherical wave.

One might object that these are mostly theoretical inferences and that we must never swear by a theory, not even by Maxwell's. Let me therefore conclude by pointing out that, so far as we can see now, the hypothesis of concentrated quanta is directly in contradiction with observed facts, *viz.*, with what is seen in the phenomena of interference.

You know that bright and dark interference fringes can never be produced by means of two different, mutually independent sources of light; we explain this by the want of all coherence between the vibrations in one source and those in the other. Now, the elementary acts of emission, in each of which a quantum is radiated, must certainly be incoherent; they may take place in different atoms, and there is not the least reason why there should be any connection between what goes on in one atom and in another. Hence, when we observe an interference phenomenon, *one* quantum taken by itself must be able to produce it, and this will enable us to draw some conclusions concerning the extension of a quantum in different directions.

In certain experiments made with highly homogeneous light, interference fringes have been observed, produced by rays whose paths differed by more than a million of wave-lengths. This means that there was a regular succession of more than a million of waves, and, since all these waves must be contained in one quantum, the length of a quantum in the direction of propagation must have been more than, say, 50 cm. That the lateral dimensions must be no less considerable is shown by the influence which the aperture of an

optical instrument has on the quality of the images, and consequently on the resolving power. Let L (Fig. 2) be the objective glass of a telescope, a "perfect" lens from the point of view of geometrical optics, so that, if there were no diffraction, the rays R coming from a distant star would converge exactly towards the focus F. In reality this can never be; on the plane V there will be an illuminated spot of a certain extent, and if we want to have this spot small, so that there is a sharply defined image of the star, we must use a large lens. As a matter of fact this is one of the advantages of the great modern telescopes.

Let us conceive the opening of the telescope to be divided into two parts, say of equal areas, a central circle $L_1$ and a ring $L_2$ around it. If, by means of a screen with a circular opening, we

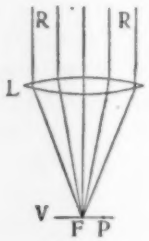



FIG. 2

reduce the aperture to the part $L_1$, the image of the star becomes less sharp; a point P at a small distance from F, which remains dark when the full aperture is used, may now be illuminated, the light disappearing again when the screen before the lens is removed. The explanation is, of course, that the vibrations which P receives from $L_1$ are counteracted by opposite ones coming from the part $L_2$. So, the fact that a large opening actually has the effect on the quality of the image which we expected from it, shows that there is interference between vibrations reaching the lens at different points of its surface. According to what we saw these vibrations must belong to one and the same quantum, and we may therefore conclude that the lateral extension of a quantum is comparable to the size of the objective.

The remarkable experiments by which Professor Michelson has been able to measure the diameter of some stars allow us to push the argument still farther. In his apparatus a beam carrying four mirrors, 1, 2, 3, 4, was placed in front of the opening of the telescope, the mirrors 2 and 3 occupying places within the opening, whereas 1 and 4 were outside the opening, on opposite sides of it. The mirrors were adjusted in such a way that two beams of rays coming from the star entered the instrument, the one being reflected

by the mirrors 1 and 2, the other by 4 and 3. The fact that under these circumstances interference fringes appear in the field of view proves that a quantum must reach from one of the outer mirrors to the other. The distance between these mirrors was no less than 6 meters.

The discrepancy between these estimates of the size of a quantum, according to which it would be too big to enter our eye, and, on the other hand, the notion that it is small enough to be captured by a single electron, is certainly very wide. Yet the laws of the two classes of phenomena about which we have reasoned, the phenomena of interference and those of photoelectricity, are so well established that there can be no real contradiction between what we deduce from one class and from the other; it must after all be possible to reconcile the different ideas. Here is an important problem for the physics of the next future. We can not help thinking that the solution will be found in some happy combination of extended waves and concentrated quanta, the waves being made responsible for interference and the quanta for photoelectricity.

# THE ORIGIN, NATURE AND INFLUENCE OF RELATIVITY*

By Professor GEORGE D. BIRKHOFF

HARVARD UNIVERSITY

## VI. The Philosophical Influence of Relativity

It is the chief function of philosophy to furnish as wide and well-balanced a view as possible of nature and mind—those antipodal aspects of the universe between which reality lies. Advances in the physical and psychological sciences have always exerted a potent effect upon philosophic thought, and the reciprocal effect has been quite as noteworthy. For a mathematician like myself it is indeed a daring project to venture, by way of conclusion, into this speculative realm, and to attempt to evaluate the philosophical influence of the recent theory of nature called relativity.

By very definition, what is accidental is without especial interest for philosophy. From its earliest beginnings it has been directed towards that which has general significance in experience. Schools of philosophy fall into two classes: the first type takes its primary model in some generality of nature, and so may be called objectivistic; the second type begins with some generality of mind and may be called subjectivistic.

The penetration of nature with numerical relationships was doubtless noted very early by man. In truth, the most useful distinguishing mark of any class of objects is its number. Everywhere in nature, and also in mind, are classes and accordingly a rôle for number. Pythagoras and his school perceived that space and time were numerical in their essence. They conjectured too that number played a dominating part in other ways; the laws of the musical string and the motions of the stars and planets were sufficient indication to them that such was the case. The keynote of their various speculations was that the universe was arithmetical throughout.

Plato was the first great subjectivistic philosopher. He took as primary the model of abstract mathematical truth. His conception of the occupation of the Deity was that of continual geometrizing. It was his great advance to have appreciated fully that there were other ideas, not reducible to number or form, and yet having the same degree of living reality; chief among them were such social ideas as the good and the beautiful. Material fact was held by him to be less real than these ideas themselves.

[1] Lowell lectures.

His successor, Aristotle, was inclined to a more objectivistic view, since he wished to ascertain the fundamental generalities by direct observation as well as by pure reasoning. He was led to the invention of formal logic, no doubt with the exemplar of geometry in mind, and defined the fields of the sciences.

Thus Greek thought advanced far enough to appreciate the penetration of nature and mind with law. Perhaps its incompleteness was most conspicuous on the subjective side.

With the Renaissance, philosophers began to examine more closely the immediate deliverances of inner experience. The familiar dictum of Descartes, *Cogito ergo sum*, illustrates the new type of starting point. This introspective attitude created an immediate extraordinary change of appearances. Descartes proposed to account for the difference by adopting a dualistic view of the universe in which nature and mind were opposed. Leibnitz envisaged instead a world of self-subsistent thought monads. Both of these men appear to have been somewhat misled by their mathematical successes, so that they overestimated the power of pure reasoning. Contrary to the Aristotelian spirit, they attempted an *a priori* treatment of the universe which seems to-day largely formal arrangement.

One difficulty which philosophy was then laboring under deserves to be explicitly pointed out, namely, the uncritically accepted notion that objects were seen even as they were in essence. For this reason, Locke achieved a substantial advance by classifying certain properties of bodies, like size and shape, as primary, and other qualities, like color, as secondary since they exist only as sensation. Berkeley's doctrine that *esse* is *percipi* went still further in the same direction, while Hume adopted the extreme position that nought was real save impressions of sense and ideas.

The psychological ideas of Locke and the physical ideas of Newton, in particular the latter's corpuscular theory of light, fixed an apparently impassable gulf between the knower and the known. Nevertheless, space and time were still held to have an *a priori* character of necessity. It was in this way that Kant, near the beginning of the eighteenth century, was led to his objectivistic phenomenalism with the knower forever separated from the thing-in-itself, and perceiving it only under space and time as a form of the understanding.

Hegel abandoned the Kantian idea of an inaccessible reality behind knowledge. He centered on the dynamic aspect of consciousness in its continual passage from the actual to the abstract. More recently, Bergson has analyzed consciousness from a similar position. For him also the starting point and goal lie in directly

given knowledge, but he finds the essence to lie in a creative evolution of thought in duration, this duration being unmodified by treatment as an abstract moment of time. Thus Hegel and Bergson achieve a return to complete Berkeleian subjectivity.

It is apparent that, from Descartes to Bergson, all the philosophers mentioned have taken their point of departure in a new psychological insight.

Similarly, the development of biological thought has been the inspiration of the philosophy of Spencer and of a whole correlated movement.

Thus it appears that the main lines of approach to nature and mind are mathematical, physical, biological, psychological and social, and constitute a kind of hierarchy. In each, a few characteristic notions are fundamental, while all else is relegated to a minor place. The following classification indicates each of these main divisions, a corresponding typical system of philosophy and some of the leading ideas:

*Mathematical*, Absolute Realism;
Class, Relation, Inference, Abstraction.
*Physical*, Materialism;
Space-Time, Matter, Electricity, Uniformity.
*Biological*, Detailed Naturalism;
Organism, Stimulus, Function, Evolution.
*Psychological*, Positivism;
Sensation, Memory, Will, Idea.
*Social*, Ethical Idealism;
Personality, Freedom, Value, Ideal.

Of these, the earlier are objective, the later, subjective in outlook. The test of the objectivity of the mathematical and physical levels in this nature-mind spectrum lies in the fact that active thought at these levels goes on without any explicit reference to mind; the thoroughgoing subjectivity of the psychological and social levels is revealed by the opposite condition; the biological level is clearly of an intermediate type.

The position of a technically developed philosophical system may fall at an intermediate level; for example, pragmatism is biological-psychological in its structure. In all philosophies, supreme "reality" is attached to the primary level, while the secondary levels are held in some sense to be derivative. For instance, on the biological level, inference is merely a process of thought which "works"; and, on the psychological level, space appears as a complex of visual and tactual associations.

The naming of the nature-mind spectrum is a matter of interest. If we are objectivistic in tendency we call it the Absolute; if subjectivistic, Knowledge.

In my opinion, the fact that these levels are independent to the extent of being largely self-sufficient indicates that the best method for the philosophic grasp of the whole is to take the various levels as of coordinate importance and reality. At least this is the reasonable philosophic view of most value for the ordinary man, even if it be merely a kind of naïve realism.

The greatest direct philosophical influence of the physical theory called relativity lies at the physical level in the nature-mind spectrum, for it affects the meaning of the fundamental terms.

The classical concepts of absolute space and absolute time are replaced by a combined space-time. Time apart from space and space apart from time lose their intrinsic significance. The new element is the event, and the new underlying basis is the four-dimensional space-time continuum of events.

The matter and electricity in space-time are now thought of as affecting its very structure. Uniformity of physical law still holds, but this uniformity requires effects in the physical realm to be locally transmitted in the spatio-temporal sense, whereas, in the older view, the "state" of the physical universe at one "instant" affected the immediately subsequent states throughout all space.

Whitehead[1] has carried the new view of nature back to the mathematical (*i.e.*, logical) level, by showing how space and time arise from his standpoint. In consciousness there is the directly "discerned" and also the ultimately "discernible." Classes of events are what are discerned, and these are interrelated through compresence or lack of compresence in consciousness. Thus an event is a "slab of nature." The technical relation between events is that of spatio-temporal inclusion. The method of extensive abstraction then yields the notion of the idealized event or point-instant as a collection of the slab-like events mutually in the relation of inclusion. The method is such that the space and time determined are clearly relative to the individual. A point is merely a collection of events with the same three space numbers; an instant is a collection of events with the same time number.

As is indicated by Whitehead, the approach to space-time given in these general terms becomes definitely mathematical under technical elaboration. In this form it is an abstraction of space-time, capable of giving the same kind of service for the new theories as various other logical systems perform for ordinary space; it is similar in structure to Huntington's system for ordinary space, in which the sphere is the undefined element, while the undefined relation is inclusion. It is on this account that the analysis belongs entirely at the mathematical level.

[1] "The Concept of Nature," Cambridge, England, 1920.

With space-time so analyzed, the object can be defined as a collection of events united by a certain kind of common modality. The aim of the physical sciences is then to specify the uniformities underlying the behavior of such objects in space-time, in terms which are essentially independent of the arbitrary method of space-time measurement selected.

It is plain that Whitehead builds in this way a mathematical approach to the new theories of philosophical type just because the general logical aspects, rather than the technical mathematical ones, are stressed.

Similarly, Bergson[2] has pointed out an interesting parallelism between his own speculations and the subsequent theories of relativity. He had taken the notion of duration, unmodified by intellectual analysis, to lie at the basis of experience. Now in the new theories the notion of the measurable interval of local time serves as the basis for the subsequent technical construction of measurable space and time. Hence relativity affords a certain independent justification of the validity of Bergson's prior conclusions. Moreover he has called attention anew to the reality of the notion of duration from the psychological point of view, in that two beings can identify themselves in thought, and so in duration. Yet there are two kinds of simultaneity, as in relativity. "The first," says Bergson, "is interior to events, it makes part of their materiality, it originates in them. The other is simply attached to them by an observer exterior to the system. The first expresses something about the system itself; it is absolute. The second is changing, relative, fictitious, it originates in distance."

If we consider the flow of time for all beings, it is clearly not possible to conceive of this multiple time as a simple flow without distorting its inner nature. To a certain extent, therefore, Bergson's refusal to treat time abstractly acquires justification.

These reactions of Whitehead and Bergson are sufficient to indicate that relativity is proving very suggestive at the mathematical and psychological levels.

Haldane[3] has attempted to apply the "principle of relativity," even at the social level, in dealing with society and the state. But here he is referring to a long established principle largely to be found in Plato, as the following passage of Haldane's makes manifest:

> The real lesson which the principle of the relativity of knowledge teaches us is always to remember that there are different orders in which both our knowledge and the reality it seeks have differing forms. These orders we must

[2] "Durée et simultanéité," Paris, 1922.

[3] "The Reign of Relativity," New Haven, 1921.

be careful to distinguish and not to confuse. We must keep ourselves aware that truth in terms of one order may not necessarily be a sufficient guide in the search for truth in another. We have, in other words, to be critical of our categories.

This is substantially only the doctrines of the differing levels of thought, stated above.

There is, however, a sense in which relativity can be made to throw further light upon the mathematical–logical factor in mind and nature, namely, as a typical instance of the abstraction. This is only the case because the familiar classical abstractions of space and time have been held sacrosanct and qualitatively different from all other abstractions. But the theory of relativity has made it clear that it is not yet possible to decide what will be the final abstract form which physical theories will take, even in dealing with space and time.

In consequence, certain elementary truths about abstract structures at any level of thought have not been properly appreciated in the past. It is to these truths, as instanced in relativity and applicable in a measure to philosophy, that I propose to turn in conclusion.

The word "abstraction" is to be interpreted here in a very wide sense. When a primitive man looked at the sun and the moon, it must have been obvious in his mind that there was a similarity about the two objects. Here the perception of likeness amid difference is the nascent intuition, the forerunner of the symbolic abstraction. The same fact in the language of the early Greeks would have been expressed by saying that the sun and moon were spherical in shape. But the entire meaning of such a statement was latent in the perception of the primitive man. Moreover, even the Greeks used various intuitions in their geometric reasoning which were not explicitly stated. Within recent years, however, symbolic logic has become available as a calculus (*i.e.*, a very brief complete language in which the words are symbols) with which to deal with abstractions. Certain postulates (*i.e.*, intuitive inferences) are stated in explicit form, and then by a chain of inferences all the latent meaning of the systematized abstraction is developed. Thus the abstraction appears in three stages: the nascent or purely intuitive stage, the stage of systematic elaboration and application, and the completely symbolic stage.

The various stages of an abstraction can be given a very simple exemplification in the abstraction of (local) time. The first stage is that in which it is perceived that the order of events will be *A*, *B*, *C*, etc. In the second stage the notions of "before" and "after" will have been embodied in the symbolic word so that *A* will be declared to happen before *B*, etc.; at the same stage it will

be held intuitively obvious that if $A$ happens before $B$, and $B$ happens before $C$, then $A$ happens before $C$—a postulate; events will be numbered, so that arithmetized time is available in dealing with events. In the final symbolic stage the notion of an instant of time will be arrived at by abstraction of the time continuum. It will be proved that with the class of "instants" as undefined elements, and with "before" as undefined relation, and obvious postulates, the time continuum can be completely characterized. This is the third and last step. The final abstraction seems to stand out and exist apart from any concrete embodiment of it in a very remarkable way.

Thus, properly interpreted, the abstraction is of transcendent importance. Only by means of the complementary process of abstraction and experiment is it possible to extend knowledge.

The first general principle referred to is essentially that given by Haldane, and may be stated as follows:

I. Every abstraction is to be applied in its appropriate domain of validity.

For example, the geometry of Euclid idealizes static spatial relations although none are exactly static. The special relativity holds only for empty space-time, and, while space-time is nearly empty of matter in certain parts, it is not exactly so. Likewise, the general relativity assumes that there is no limit to the indefinitely fine structure of matter.

However, all these particular abstractions apply at the physical level. At the other levels the abstractions used are far less exactly applicable, in particular because the meaning of the various terms is not susceptible of equally precise technical definition.

This seems to be more or less in the nature of the case, since only physical entities are presumed to be elementary, while those of biological, psychological or social type are statistical (although not less important on that account).

II. As more complete abstractions are made, they may be expected to include their predecessors.

Thus, in a sense specified previously, the special theory of relativity includes the classical theory, as the case of very small relative material velocities; and the general theory of relativity includes the special, as the case when matter is very sparsely distributed.

In general, the advances in the physical and psychological sciences, as well as in philosophy, suggest that new abstractions contain their predecessors in some sense or other.

III. The undefined elements, relations and postulates of a particular abstraction are to a large extent arbitrary.

For example, the solid may be made the element in ordinary geometry, as well as the point. In the latter case the undefined

relation may be "betweenness" or "separation." Similarly, in relativity we may take the four-dimensional extended event or the point-instant as the element; and in the latter case the undefined relation may be "local time" or "local distance." The range of choice is always very large, and there are many interesting possibilities besides those referred to.

Hence, even though the undefined elements, relations and postulates are selected so as to have a large degree of self-evidence, the choice made is by no means determined by this requirement. If two available sets of undefined elements, relations and postulates are considered, either can be completely interpreted in terms of the other. Hence actual difference in conclusions does not follow from the difference of terminology. The essential item is that all elements, relations and postulates from the one system can be systematically interpreted in the other, and *vice versa*.

On this account, the fact that there are many philosophical systems does not necessarily imply any essential differences between them, except in so far as the meaning of the terms used can not be consistently interpreted back and forth. For example, suppose that one philosophical system regards as real only what lies at the physical level, and a second such system holds to the superior reality of the psychological level. Notwithstanding this difference, it may be possible for either to interpret technically the kind of reality used by the other. The mere difference in usage of words is not significant. Of course, if the abstractions have reference to ascertainable fact and differ in a substantial way, experiment will reveal which of the two is correct. However, since systems of philosophy do not differ about the facts at the various levels as much as about their interpretation, it seems patent that such systems may be abstractions with different undefined elements, relations and postulates, but otherwise in satisfactory harmony.

IV. The usefulness of an abstraction is relative to its inherent simplicity of structure and its agreement with the facts.

For example, the usefulness of the theory of relativity depends on the circumstance that it possesses the same inherent simplicity as the classical theory, while it explains more facts than that theory did.

Similarly, a philosophical system possesses merit only in proportion to its simplicity and capacity of accounting for the facts of mind and nature.

Thus the true rôle of the systematized abstraction becomes apparent, and freedom is won to use a formula or theory and yet not be enslaved by it. Undoubtedly relativity has acted as a salutary influence in this direction upon the entire field of human thought.

# THE SOUTH AMERICAN INDIAN

By Professor WILLIAM H. HAAS

NORTHWESTERN UNIVERSITY

More or less periodically, newspapers give considerable space to the discovery, somewhere in the western world, of fossil bones, purporting to be human or prehuman, of great geologic age. Patagonia is a good place to have such bones discovered, for the region is sufficiently unknown to most people to be more or less clothed with strange possibilities. Not long ago such a report again emanated from there, and a little earlier from this general part of the world came also the story of the living plesiosaur, the held-over Cretaceous reptile. Such stories are common and, having a grain of scientific truth in their write-up, make good newspaper copy. They belong, however, to the same order as the discovery of a living mastodon in Alaska, or to the seeing of an enormous sea serpent off the Atlantic coast.

The latest South American find is a skull purported to be from the *early* Tertiary. This find, if authenticated as to age, would be a most startling discovery and well worth a place on the front page of any newspaper. Fossil human records of late Tertiary (late Pliocene) age are established and fossil human bones in South America also are known, but to find such bones of Tertiary age in South America would seem an impossible combination.

From geologic history we are led to believe that the same animal form originates but once, and that its birthplace, so to speak, is in a rather restricted area. From this center the animal may spread until prevented by barriers, or it may become adapted to new environments by physical changes. We are not sure of the exact birthplace of man; most probably it was in southeastern Asia; but we are quite sure that it is not in either of the Americas. Therefore, to find a Tertiary man in South America would mean, to say the least, a most astonishing migration and early dissemination. That there may have been early migrations to the American continent and that the migrants may have become extinct is a possibility. Professor Osborn recently reported on the finding of a remarkable tooth in Nebraska taken from the middle Pliocene which shows wear both by use and by erosion. The tooth is not like that of a gorilla, gibbon or orang, but most like that of a chimpanzee, and is thought to be intermediate between ape and earliest man. This anthropoid may have been part of that large migrant group of Asiatic fauna

recently unearthed in our west. The tooth was found with the remains of rhinoceros, camel, Asiatic antelope and an early form of horse. This is the only specimen of the primates discovered on the American continent and has been named Hesperopithecus haroldcookii.

It must not be concluded from the discussion above that man's early development was along such a narrow line that a chance death of an individual or even of a whole species might have eliminated all that the human tendency had in latent store. Just as many species and several genera of horses developed and have been found fossilized on our western plains, so we know, according to the classifications made, at least four genera and six species of man in fossil record from the Old World. In the case of the living horse group, we have only one genus and four separate species remaining, *viz.*, the horse, the ass, the zebra and the quagga. The latter is probably extinct now, also. In the case of living man, we have only one specie remaining.

The difficulty of determining the age of fossil man accounts in part for the credence given to stories concerning him. To say that a fossil belongs to this or that formation or period is in most cases not difficult because the determination is only relative. However, in determining the age of human fossils, a determination which demands great precision, the problem takes on an entirely different aspect. Man is so very recent geologically and requires such precision in his age determination that the ordinary methods used may lead to very divergent conclusions.

The age of rocks and the fossils in them is determined by the very simple principle that younger rocks are laid down on older. Accepting this so-called "law of superposition," we can trace in the fossils contained therein certain biologic lines of descent through the rising stratigraphic column. After a line of descent once has been worked out, such a record with some of its associated fauna can be used as time markers for other regions. With man, however, other fossils are of little value because little change has taken place in their forms since his advent. Likewise, the upper part of the stratigraphic column has been divided and subdivided into such great detail, relatively, that slight differences in interpretation may lead to conclusions wholly irreconcilable.

In the case of man there are other difficulties as well. Man is a digging animal, and there is always the question of a possible introduction subsequent to the formation of the matrix which encloses the bones. Also all the older fossilized human bones have been found in alluvial deposits where they have been laid bare by erosion. Through erosion or slumping the bones may have been

carried to a much lower level than the one originally buried. The later human fossil record is from caves where the determination is made largely on the basis of the bones of other animals associated with the remains. Even if these and other questions are satisfactorily settled there still remains the interpretation of the fragments in hand. As a rule, so little of the original is left that a true reconstruction in most cases is highly improbable. One of the finds in Argentine, which at first created so much interest throughout the world, owed its scientific publicity to the fact that Ameghino, its sponsor, in his drawings, had given the skull an orientation which, when other scientists went there to study the find, could not be accepted. Besides, in most cases the determination is made from a single specimen and in such a case we can never be sure that the specimen in hand is a true representation of the degree of development of that period. The characteristics noted may be due merely to an abnormality, or to a reversion of this particular individual.

In the new world many finds of various geologic ages have been reported, but none have been accepted generally as establishing either Pliocene or Pleistocene man. In South America there seems to be a predilection for the Tertiary, in this country for the glacial period, yet, without great reservation, no fossil record, except that of the modern Indian, can be accepted. Europe, we know, had its glacial man, but, so far as we know, the glacial period did not disturb any human beings in the new world. There was no race here preceding the so-called American Indian, and he, it is generally accepted, must be thought of in terms of cultural traits rather than in terms of organic evolution.

## Cultural Evolution

The study of the origin and evolution of the American Indian is at present much neglected, especially by the student of geography, in spite of the fact that here is one of his richest fields of research. This neglect is all the more serious because the old cultural traits of the red man rapidly are disappearing, and the field for research is becoming increasingly more difficult. Cultural as well as physical evolution is clearly the result of environment, and nowhere else can this influence upon cultural evolution be traced so clearly and so sharply as upon our American Indians. They are the real creatures of their surroundings, and at the advent of the white man still lived in the same general environment under which they had developed. These conditions, however, have been gradually changing due to the influence of the white man.

The white man has brought a new cultural environment. In

this country the Indian has been shifted very largely from the region of his ancestors and put under new physical conditions. In South America, where the white man and the Indian have intermarried so freely, the two orders blend; yet the influence is dominantly that of the white man, since the Indian has adopted many of the ways and products of the more powerful race, although he is still in the same general physical environment. His fate no longer is in his own hands, and he lives and acts under the direction and influence of another culture. Only in parts of the Amazon Basin can any considerable group be said to be untouched by white influence.

In the study of our own progress it is interesting to speculate as to what effect slight differences in our cultural environment would have had. What would be our status had there been no such minerals as iron and coal. What we owe to the horse, or even the lowly silkworm, are not easy questions to answer. If there had been no such animal as the hog or plant like corn, what would Chicago be like? If Mars is inhabited by a highly cultured race, did the Martians pass through the stone, the bronze and other ages? Do they have something which they use as exchange, over which we worry so much when we have it and still more when we do not have it? Is their life organized on the individualistic basis like our own, or is it communistic like our Indian civilization? Do they emphasize the things we do, or have they a different viewpoint? Such questions can be multiplied without number, perhaps to no purpose; yet that situation is exactly what the European saw, but didn't appreciate, when he first set foot on the new world. We haven't appreciated the fact fully yet that here in the new world had evolved a new culture which paralleled the European in time, but was as different in kind as was the environment which produced it.

The white man not only had an opportunity to study a living civilization almost as distinct as though it had been located on another planet, but also saw what were, even then, antiquities of other civilizations that had risen and disappeared. It never occurred to him that here was a civilization that had risen without the use of minerals and without beasts of burden. He did not realize that here was a culture that had surpassed his own in social organization. To him the Indian was merely a savage, and the white man was naïvely ignorant of the fact that most of the savagery was practiced first on his own side. Even to this day, in the minds of many people the words "Indians" and "savages" are synonymous. Had the history we read been written by the red man the story would be a different one. To the Indian, on the

other hand, the white man seemed of a low order, for the paleface made treaties seemingly only to break them. Why should he promise so much and live up to so little? The Indian never could understand the white man's insatiable greed for the yellow metal for which he was ready to lie or steal or murder. To the plateau Indian of South America gold had no value except when made into objects of art and worship. The white man not only took these objects, but set out at once to destroy their value by melting them down into shapeless masses. One civilization had made values that the other knew nothing about. The use of gunpowder and lead and treachery saved the day for the one and lost it for the other.

The general notion has been long too common that the Indians, wherever found, were savages without any development, and that regions like Peru, Central America, Mexico and our southwest must have been peopled by a race, or at least a strain, of greater actual potential possibilities in order to have advanced along certain lines beyond those of other sections. Careful study has shown this not to be so. Each region produced its distinctive culture according to its environment with a minimum of outside influences. The Indian was limited in his migrations to the distances his own feet could carry him. All his supplies and the fruits of his forages were transported on his own back, for he knew not the use of the wheel, nor had he domesticated any animals sufficiently strong to carry him. Consequently, his migrations were limited to the regions sufficiently similar to furnish the kind of food to which he was accustomed. Thus, each type of food-area produced a culture which was a distinct product of that area. Because the southwest Indians built homes of a thousand rooms does not make them more civilized than the plains Indian with his skin tepee, or the eastern forest Indian with his block huts. The fact is the one was skilled in one line while the other had advanced in another. The difference between the agricultural Indian of the plateau and the roving hunter of the plains was largely a matter of emphasis. In point of view it was a difference between one who travels and one who stays at home. In the case of war there isn't much doubt as to which of the two would win. We can not use our civilization as a measuring stick in gauging another which climbed a totally different ladder; nor can we select one Indian trait and measure all other groups by it. The Indian wherever found was a product of his particular environment and did not show by cultural traits different innate ability.

Accepting this point of view, many attempts have been made to group Indian cultures around some fundamental principle. The problem, however, is not simple, for many factors enter into what

THE RUINS OF PACHACAMAC, NEAR LIMA, PERU

These enormous structures were built of adobe, the common material available. Here are found the huge underground cisterns, some of which are still in excellent condition.

comes under the general name of culture. From an evolutionary point of view, the most satisfactory working hypothesis seems to be that based on the type of food used, for its search, as an ever-present urge and not to be pretermitted, directs most of the primitive activities. The nature of food available is also most closely allied with topographic and climatic conditions, especially with the natural plant and animal life. Conversely, the life of a region, including primitive man, gives, in the main, the best all-round view of the physical environment. Since physical conditions vary from place to place, so food possibilities also vary and, similarly, culture also will vary.

The number of culture areas under primitive conditions will depend, therefore, on the number of areas which produce, in general, the same type of food. Such areas thus become natural or geographic regions, limiting, in the main, migrations. Wissler[1] divides South America into four culture areas. These areas again may be broken up because of minor differences within the group.

[1] "The American Indian," J. Clark Wissler, New York, McMurtrie. This most excellent book takes up both continents and contains a wealth of basic information.

THE BURIAL GROUND AT PACHACAMAC

Peru, in order to keep minor antiquities at home, has prohibited their exportation. As a result no excavations are made by reputable organizations; but individuals dig and destroy to their heart's content in search after gold and silver ornaments to be sold surreptitiously, perhaps to be melted down. Embalmed mummies, wrapped in valuable old cloths, and other relics strew the ground.

At the present time, of course, in many sections, conditions are entirely changed; yet where the Indian blood still remains these conditions remain more or less the same. The divisions are as follows:

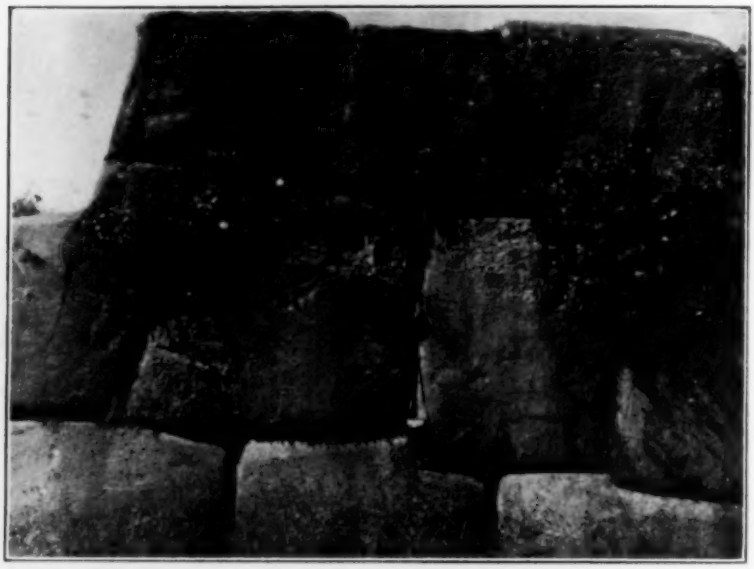
The Chibcha area, which included also part of Central America, centered around Bogotá. These people were agriculturists, growing potatoes, beans, maize and other minor food products. They grew cotton also and had developed a high technique in spinning, weaving and dyeing. There were great markets where a kind of currency was used. Taxes were paid in gold and cloth. To facilitate marketing, roads were built and suspension bridges crossed many rivers. They had no beasts of burdens nor knew the use of metal tools. Their advance seemingly had been reached until some new factor should find entrance into their lives.

The next group developed around the manioc of the Amazon Basin and was, therefore, largely agricultural. It is to be remembered that South America is largely tropical and that fully one half of it lies within the Amazon basin. Most people think of tropical wilds as a place where food is extraordinarily abundant,

THE RUINS OF THE GREAT INCA FORTRESS, SACSAHUAMAN, AT CUZCO
The enormous size of some of the stone blocks may be estimated by the size of the man in the middle foreground. One block is said to measure 27 ft. by 14 ft. by 12 ft. This stronghold may be older than Cuzco itself.

but nothing is farther from the truth. The idea is common because of the luxuriance of tropical growth and the prolificness of a few plants. Food in its natural state is not abundant, either animal or plant. Because of the lack of native foods, agriculture had to be practiced, and manioc, or cassava, was the chief crop, taking the place of the maize of other sections. Besides this, the Indian grew sugar-cane, peppers, pumpkins, tobacco and other minor products. Here, as elsewhere, the environment determined the traits, and the conditions were too severe to develop anything unusual. Without going into detail, it may be well to state that the supposedly enervating conditions of the tropics did not have a particularly debilitating effect upon the natives, for they largely had become immune to the native diseases. Whatever, at present, the effect on the white man, one needs only to recall the names of the two leading tribes, the Caribs and the Arawaks, to bring to mind the virility of these groups. These tribes were equal to the Araucanians of southern Chile, and surely superior to the Quechua and Aymará of the Inca Empire.

The third culture group is that of the plains of the south. It has received its name from the dominant animal of the pampa,



A PART OF THE WALL OF SACSAHUAMAN

The building of this fortress is considered the greatest achievement of man in America. The great size of the stones and the precision with which one was fitted upon the other, so that not even a knife blade can be thrust in between, places this well into the front rank of American antiquities. The carrying case hanging in the middle foreground is for a number 3 kodak.

the guanaco. This fleet little animal is one of the camels that had migrated from the northern into the southern continent, and became adapted to the plains, whereas the llama, alpaca and the vicuña are the product of the plateau. The guanaco culture is much like that of the buffalo culture of our plains Indian. They both depended on the chase; where the life of one centered around the buffalo, that of the other could not have existed without the guanaco. These hunters did little with crops or with weaving but developed great skill in leather work. After the Spanish introduction of horses and cattle, the life centered around the horse, and there developed what has been referred to in our own country as "the horse culture." As might be expected, the pampa developed some features not found in North America, such as the bola, the lasso and the toe stirrup. There were many minor differences also, such as the tepee's giving way to the lean-to, or to the tent with the ridge pole, but the similarity is much more striking than the dissimilarities.

The fourth group is that of the Inca Empire. The northern border of this area is in Ecuador and the southern in Chile. The

AN OLD INCA ROAD LEADING OUT OF CUZCO

These roads were not built for vehicles and in certain places resemble a stairway more than a road. The group leaving Cuzco is, on the whole, typical.

culture is a highland one, yet evidences of it are found in the lowlands. The dominant languages were the Quechua and the Aymará, and these tribes make up the dominant stock to-day. They had a highly organized government in which authority was vested in a council which appointed from a hereditary group a war chief or Inca. Hence the name. Agriculture was highly developed, both in variety of products grown and in amount of production. The main crops which they irrigated and manured were maize, potatoes, manioc and peppers. They had domesticated animals such as llamas, dogs, guinea pigs, monkeys and birds. Some of the animals were merely pets. From the cotton grown and from the llama and vicuña wool, they spun beautiful cloth showing exquisite taste in their elaborate weaving designs. All sorts of clay work reached a high degree of perfection. Gold, silver and copper ores were mined and smelted and even true bronze was

CUZCO, THE ANCIENT CAPITAL OF THE INCAS,

as seen from the road to Sacsahuaman. The town is still the Mecca of the Indians of Southern Peru, some of whom are said to salute it still as in the days of old. Parts of it bear out the appellation of "one of the dirtiest cities in the world"; but it is also one of the most interesting cities where both ancient and modern pique the curiosity of the traveller.

made. They built roads and suspension bridges. There was no writing, but they had counting devices. There was an organized priesthood with confession of sins and religious orders of virgins. They had also a deluge myth and offered animals as sacrifice to the sun god. This was the civilization torn by internal dissension to which the gold-crazed Spanish Conquistadores came.

All these culture groups, each with a fairly definite unity of culture but shading out at the borders, were the products of conditions under which they lived. The strange part of it is that the best and most virile stocks, like the Caribs, Arawaks and the Araucanians, had not risen the highest according to the white man's standards. They left no enduring monuments to their industry and skill such as have been left by the more mediocre plateau

A Doorway of Ollantaytambo in the Urubamba Valley below Cuzco

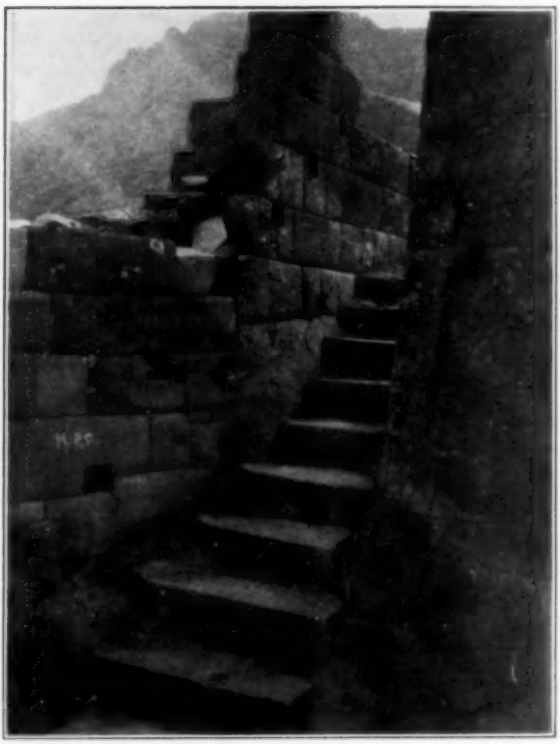
This fortress is believed to have guarded the plateau peoples from the savage hordes of the montaña along one of the easiest passes. With great care each stone was lifted upon these below. Machu, Picchu and Rosaspata are still farther down the valley.

groups. This easily is explained by the fact that such monuments are the result of group activities and that group life is the result of a congestion of populations. This congestion, in its turn, under primitive conditions, may produce a certain degree of degeneration. This thorough adaptation of a large group to the region which it occupied shows conclusively that the Indian can not be a recent immigrant spreading rapidly over the two continents. His very provinciality and evident lack of transferred culture emphasize his early distribution and adaptation. The use of certain customs or leftovers by widely separate groups, on the other hand, clearly points to a common origin.

THE GREAT FORTRESS OF PISAC

was built at the upper end of the Urubamba pass. This structure never was finished. The rows of stones at the base of the walls were never put in place. Here are some of the most remarkable series of terraces. Every foot of ground that could be terraced and cultivated was made to produce its share of food. Some of the terraced slopes may be seen in the background.

Accepting that the Indian advanced in one direction or another according to the conditions under which he lived, there are still many questions to be answered: What was the original culture from which all these variants sprang? It has been demonstrated quite satisfactorily, to many students at least, that the American Indian is closely associated with certain hill tribes of eastern Asia. Granting that the early immigrants came from there, we must ask, were they all from one stem, and granting this, were they all from one migration? Here many difficult problems clamor for a solution and the most vital of all in the study of Indian culture is, What did he bring with him and what did he develop here? There are various possibilities in the degree of culture attained by the time he became a migrant to a new world. He may have left early, at the very threshold of his cultural career, and having become separated from his fellow-man by geological changes, he may have become culturally fossilized, somewhat after the manner of the primitive mammals of Australia. This would seem strange, since the country is so large and conditions are so variable . There doesn't seem any



A Stairway at Pisac

It is hard to believe that these stones were dressed and fitted into place with no other than stone tools.

lack of stimulation to peoples at the present time. On the other hand, he may be a relatively recent arrival from a degenerative stock bringing with him fundamentals that led him into blind alleys. Unfortunately, we know so little of the hill stock of eastern Asia that the answer to the question seems insolubly to be bound up with the anthropological investigations of that part of the world. With a greater knowledge of the Asiatic culture we may hope to answer some of the questions seemingly unsolvable to-day.

A host of other problems also arises, and the whole question relative to the differentiation of Indian cultures becomes most complex. Even if the ancestors of the Indians crossed over from Asia early, in one group from one stem, how and when did this migration occur? Did the dissemination throughout the two continents come suddenly in another Tower of Babel way, or were there many departures from the original center or centers separated by long intervals of time? After one culture had been established did an-

THRESHING GRAIN

gathered from the terraced slopes near Pisac. The Biblical injunction of the laborer being worthy of his hire is evidently not needed here, when in some of these valleys, it would not be hard to make-believe that time had dropped back into the days of Abraham.

other come and displace it, similar to the Hun invasion, and did this culture, in time, pass through the same development that its predecessors did? If similar traits are found in widely divergent groups does that mean a sameness of origin, a sameness of conditions, or a sameness of something else? Or did these similar traits come into existence separately and absolutely independently? Our knowledge of the American Indian is so meager as to leave most of these questions unanswered.

We do know, however, that evolution is an extremely slow process. Social and cultural as well as physical evolution is, in the main, largely through mutations. Cultural traits, when once established, are most resistant to change and, as has been shown in so many ways in the history of the white settlements in this country, the whole social fabric is transplanted *en masse*, and such social customs survive in the new environment long after the conditions which brought them into being have passed away. New things come only with pressure and this never becomes very strong until populations become fairly dense and the few resources laid hold of no longer supply the needs. Progress comes with the laying hold

IN THE CUZCO VALLEY

alluvial fans offer excellent crop conditions. The soil is rich and the substratum is kept moist by the run-off from each little shower. The widespread use of the steep hill slopes, as well as the flatter hill tops, is a never-ending surprise.

of the untouched resources of the region and the more effective use of the old.

Probably the greatest factor in the relative stagnation of the American Indian was the sparsity of population. The continents were large and the time, probably, had not been long enough to give a dense population. The culture groups also were so much larger than the tribal units that intertribal killings kept down the number. Perhaps the greatest factor of all was the relative infertility of the Indian woman and the extremely high death rate among young children, if one can judge by present-day conditions. The few advanced centers of a more advanced culture were peopled, most likely, by weaker and less competent tribes driven from the better sections. These tribes, freed from intertribal killings through natural barriers and situated in regions where nature makes a lack of sanitary conditions least dangerous, may have multiplied to such an extent that necessity became the mother of invention and the tribes became somewhat expert along lines in which past experience became cumulative.

Whatever the absolute facts, evidence from several fields points to certain definite conclusions. The so-called American Indian is

A PART OF THE HIGH PLATEAU OF PERU

along the route from Oroyo to Cerro de Pasco. The stones have been gathered into rows and piles and the land formerly worked between them. So much gathering of stones has been done that many natives of the region insist in all seriousness that the Indian still piles stones just for the sake of piling.

of mongoloid stock reaching the New World with the cultural background of the stone-polishing stage. According to Hrdlička[2] "the immigration, in all probability, was a dribbling and prolonged overflow, likely due to pressure from behind, or want, and a search for better hunting and fishing grounds in the direction where no resistance of man yet existed." There may have been, and most likely were, small accretions later on both sides of the continent; but, if so, no definite new elements of culture were added.

If this be accepted, then the culture of the American Indian is almost an entire cultural product of the New World. Just how old this American culture is can not be stated, even in relation to the white race, for the stone-polishing stage for Asiatics was not necessarily the same as for Europeans. At any rate, the progress made by the American Indian in the various arts was extraordinarily slow in comparison to those in his mother continent. That the culture of the American Indian is an American culture is not hard to believe, but that the Indian lived here quietly and com-

[2] Hrdlička, A., "The peopling of America," *The Journal of Heredity*, Vol. VI, pp. 79–91. (1915).

STONE FENCES AND STONE HOUSES WITH THATCHING

brought up from the montaña is a sight which emphasizes the barrenness of the plateau and the severity of the living conditions. This is an Indian village along the route to Cerro de Pasco.

placently for 25,000 years[3] or more while civilization rose and fell in each of the Old World continents does not seem credible. Such, however, seem to be the facts. The slight development, relatively, of the American Indian is one of the most interesting but most difficult problems to solve pertaining to the New World.

### THE INDIAN OF TO-DAY

During the period of exploration and colonization, the native was looked upon by the white invader either as a nuisance or as an aid. A good Indian was either a dead Indian or a slave. In sections where land was the thing wanted for homes, the red man had to be displaced, of course, for the land could not be occupied by the white man as long as it was needed for a hunting ground. The two interests were unalterably opposed to each other, and the result was many wars and much bloodshed. The Indian, however, inevitably had to yield before the oncoming hordes and he did it little by little, rarely in friendly spirit and with little mixing of blood. The few mixed bloods in Anglo-Saxon America came largely through the life-habits of the French voyageurs in the great in-

[3] See Osborn, "Men of the Old Stone Age," p. 23.

THE "VILLAGE GREEN" OF THE PRESENT-DAY INDIAN VILLAGE OF PISAC
The weave of the "poncho" and the shape of the headdress never fail to tell where the Indian comes from. Styles never change and the badge, therefore, always tells.

terior, although at the present time in the southwest, due to the finding of oil on reservations, there is perhaps more mixing of blood than at any previous time.

In Latin-America, in the main, the conditions were different. There the Indian, for the most part, was more valuable as a slave than dead, and there was no desire or need to dispossess him. The males were wanted for forced labor in the mines or in the sugar fields, the females for servants and concubines. There were no restrictions, and miscegenation could and did go on freely. In the West Indies, only after the Indian had been killed off by slavery was the negro imported. In Brazil the conditions were even worse because of the slave drives from the rich recruiting fields near by. The coast of Brazil, for a time the sugar source of the world, gained its rank at first under Indian and later under negro slave labor. The "bandeirantes" of southern Brazil are famous, perhaps infamous, for their Indian enslavement expeditions. In Argentina, due to the lack of development, aside from the cattle industry, the Indian was crowded out rather than absorbed, as he could not be used. Modern progressive Argentina may be said to begin about 1870, and in 1879 there was an Indian drive to wipe

INDIAN WOMEN SELLING FRUIT

and other eatables to passengers and train crew at a station stop of the famous Lima-Oroya Railway. Trains usually stop long enough to do considerable bargaining for products on sale. Eating and travelling are hardly to be dissociated in South America.

out the last Indians. The country, therefore, is fairly free from Indian blood except in the south and in the northwest. In Chile, likewise, the Indians were warred upon as early as the first half of the sixteenth century by the Spaniards in their thirst for treasures; and the brave Araucanians, fighting for their freedom, little by little were forced south into the more inhospitable parts where they still are and slowly are becoming absorbed. The number of mixed bloods, although greater than in Argentina, is nevertheless much smaller than in the countries to the north.

In the plateau regions the situation was quite different. Here on the bleak, timberless, grass-clad punas had developed a culture not aggressive, but quiet and docile, trained to follow a leader. They were an agricultural people holding their lands in common. No one owned anything and there was no need for currency. The lands allotted to the widows, orphans, sick and aged and to the absent soldiers were cultivated first. A story is told of a superintendent who was hanged because he caused the land of a relative of his to be tilled before that of a widow. There were no beggars because he who would not work was punished. Tribute and taxes

THE PUBLIC INDIAN MARKETS

No better conception of the products of the country can be obtained than at these, and none is more important than the produce and live stock market at Clisa, Bolivia, below Cochabamba on the eastern slope of the Andes. Products sold here may have come from places several days' journey distant.

were paid to the government from the products of the land. Huge granaries were built for the storage of food against the time of need. Physical comfort for all was sought. There was nothing to long for, and it was stupid to be ambitious, for this kindly, beneficent and paternalistic form of government took care of everything.

Into this community life came Pizarro and his men in 1532 with fewer than 62 horsemen and 102 footmen. The Inca kingdom had just been wrenched in twain by civil war. To Huascar, the legitimate heir, had been left the southern three fourths of the kingdom, and to Atahualpa, the illegitimate, though victor, was left the rest, with Quito as the capital. There is no need of retelling the story, so well told in Prescott's "Peru." Whether the stories of the immense treasures of gold found there are true or not, it matters little now. It is true that a handful of white men took what they wanted, murdered the men, raped the women and enslaved them all —a slavery which, in spirit, is just as real to-day as it was in the day of Pizarro.

Their long history makes their present condition especially pathetic. Although by no means clearly established, various epochs

A Breakdown in the Bolivian Montaña

The automobile following along a river bed aroused considerable curiosity, especially when sufficient time elapsed for the news to spread.

of culture have been worked out. Their earliest group advance is believed to begin about 200 B. C. with the development in certain valleys upon the plateau. From this time up to 800 A. D. is given as the period of development. From 800 to 1150 differentiation due to growth seems to have taken place. This is thought to be the period of the Tiahuanco culture, a period in which Peru attained its highest degree in architecture and sculpture. From 1150 to 1530 is the Inca era, and during this period came about the fusion and the building up of a great empire. After this came the Spaniard and the deluge. Bishop Oldham, of South America, characterizes the condition of these people as the saddest, the most pathetic and the most hopeless of all peoples.

The complete overthrow came because the "Conquistadores" married into the royal Inca family and in one case, at least, an Inca prince married a Spanish woman of rank. The white man,

THE "TARJETA"

The people on the Bolivian plateau are hard put for fuel. The "Tarjeta," a woody mushroom growth, is brought to the railway station or town and sold by weight.

in the minds of the native, thus became associated with royalty and received the same homage and respect. Even to-day in some sections, the natives, both men and women, in passing, will step out of the road and uncover in deference to the white man. With the conquest, however, nationality was destroyed and, instead of a beneficent and paternalistic government, came one of despoliation and exploitation. Organization disappeared and the fundamental arts in the activities of the people were broken up. The great dams and irrigation ditches built by the labor of thousands slowly went to decay and then became useless through neglect. Roads went out of repair and soon became impassable. The temples were sacked and desecrated and the people were forced to abandon their own religious life and take over bodily new forms of worship. This, of course, was done only outwardly, so that, even to-day, the

PREPARING POTATOES

To prepare potatoes for food in a region when the boiling point of water is low and the cost of fuel high, the Indian has solved his problem by freezing the potatoes and then working out the surplus water. Although all three women in the middle foreground were busy preparing their "chuño" the one in the center worked with such lightning activity that an exposure of a fiftieth of a second was not rapid enough to prevent blurring.

church, in many sections, is little more than a pagan institution with a Christian setting in which a weird mysticism and the strange masked processions of bacchanalian (holy) feast days form a leading part.

This miscegenation from the top down has gone on apace so that to-day there is absolutely no way of distinguishing among the native-born which are pure-bloods, either white or Indian. Such a classification, nevertheless, would be meaningless, for the difference recognized locally is not one of blood, but one of position, rank, or opportunity. There is a general recognition, however, of three classes: (1) the "gente" or gentry, mostly white who live to be served; (2) the "mestizos" or "cholos," the mixed bloods or artisan group; and (3) the "indios" or "indiada," the agriculturists. In Bolivia, one of the most distinctively Indian countries, the pure white population, excluding foreigners, is perhaps less than 5 per cent. The census of 1900 gave 14.64 per cent., but these figures, it must be remembered, do not give the true blood situation, but

AN INDIAN VILLAGE OF THE MONTAÑA OF PERU
There are said to be more hogs than people in the village and act as the street-cleaning force.

rather that of rank. Of the mestizo, or mixed class, the number varies in different sections: 8.13 per cent. in the department of La Paz to 51.54 per cent. in Cochabamba. The same census gave the Indian population as 48.42 per cent. of the total, with the highest in the department of La Paz, 75.61, where the amalgamation of the race has been the least.

Their sad condition and the lack of progress are not due to laziness or lack of energy. They are extraordinarily industrious, yet get nowhere. One is impressed with the futility of their movements. The amount of work done in terracing and gathering stones into heaps and walls is astounding. In some hilly sections literally every available foot of soil has been preserved, walls have been built and earth carried to complete the terrace. So many stones have been carried into piles that some of the people there tell one seriously that the Indian will pile stones for no other purpose than just to make a pile. In many sections the picture that remains with the traveler is not of young, undeveloped countries but of old, overdeveloped, decadent lands. The industry of the women is the most striking. They are rarely, if ever, seen in the open with idle hands. A woman may be driving a group of llamas, may have a bundle of fagots on her head, a bundle of produce on

her back, within which sits her babe, yet her hands are ever twisting the spinning spool. Neither is it a slow, leisurely walk, but ever a little toddle or dog trot with little movement of the body except of the hands and from the hips down. Occasionally a young man may be seen spinning, also.

Their industry, however, is of little avail to their good, for the Indian, in general, is considered only as a part of the soil. He is a gift of nature like the plants that grow on it. If he has a wife and children they also form a part of the landowner's man-power. If the Indian happens to have sheep or llamas or chickens, these also may be commandeered by the "patron." He has few or no rights in court. The woman's lot is especially hard, and morality, as we know it, scarcely exists. Women too old and girls too young to bear children, from all outward appearances, have suckling babes at their breasts. An American doctor in Lima who knows the interior was emphatic in his statement that fully 80 per cent. of the children born succumb the first two years.

The Indian's life is without hope. "Whatever is is a necessity," seems to be the philosophy, if there is one. Whatever is custom is also a necessity. He knows that his fathers lived exactly as he does, his burden may be a little heavier, but there is still "chicha" to drink. If there is any thinking it is at once dulled by the chewing of the coca leaves. If there is no food the coca again supplies the need. The priest, keeping close to his traditions, has assured the Indian of the church's divine mission, and has imbued his mind with the thought that he was made to serve his masters. In his superstition he must pay to save himself from perdition. He, therefore, is kept in debt both to the "patron" for "chicha" and coca, to the church for prayers, and, in time, looks upon debt as a matter of course. The church has a great appeal because of its feasts and its imagery, and could remake the life of the Indian if the priests would. Concepts of fatherhood and love, righteousness and justice can have no meaning so long as such things are outside the pale of his experience. But an image of the virgin or a saint, in church or carried along the country road, is reverenced most pathetically. To see an old barefoot man or woman in tatters kneeling before some shrine, oblivious to the world about, talking and gesticulating as the tears roll down the cheeks, is a picture not soon forgotten.

Education, seemingly, is the only thing that can save the race, and, for that matter, the plateau nations. The Indian has the ability, but hope has been shut off for so long that only the exceptional one rises above his environment. There have been Indians at the head of affairs in Peru and Bolivia. Those that

have risen have had chances of which others have not known. However, the vital thing is not the exceptional one that rises but the mass that lives without vision. The problem of education is not a simple one. In a country where the white lose caste by associating with the Indian, education can not sift from the top down. On the other hand, if education must come up through the Indians themselves, how can it get started? This is a most serious problem. The few teachers outside of the leading centers are rarely competent, although for the most part very serious-minded and anxious to learn. Few of them even know the multiplication table or have the other rudiments. Outside a few cities, there are no schoolhouses worthy the name, and the governments are months in arrears in the meager salaries of the teachers.

Surely a nation can not prosper where fully 90 per cent. of the people are considered of an inferior order by the ruling few. Democracy can not exist where public sentiment is unknown and where a leading official in a medium-sized town can not grasp the meaning of the phrase "public opinion." At present in many sections of the plateau there is no public sentiment, for where only an elect few can read, newspapers are shorn of their power; and the pulpits, the great disseminators and crystallizers of public opinion in this country, are unknown in Latin-America as such. The church, moreover, shows little or no interest in social betterment. In many sections, however, times are changing and there seems to be a growing consciousness of injustice and at the same time of power. In the larger centers local uprisings of the "indiada" occur with more or less frequency and are put down as regularly by the police force, from the same class, in the employ of the government of the few.

The hope of the plateau nations undoubtedly lies in the education of the mass of the people. Dr. Tello,[4] a Peruvian Indian, educated at Harvard, believes:

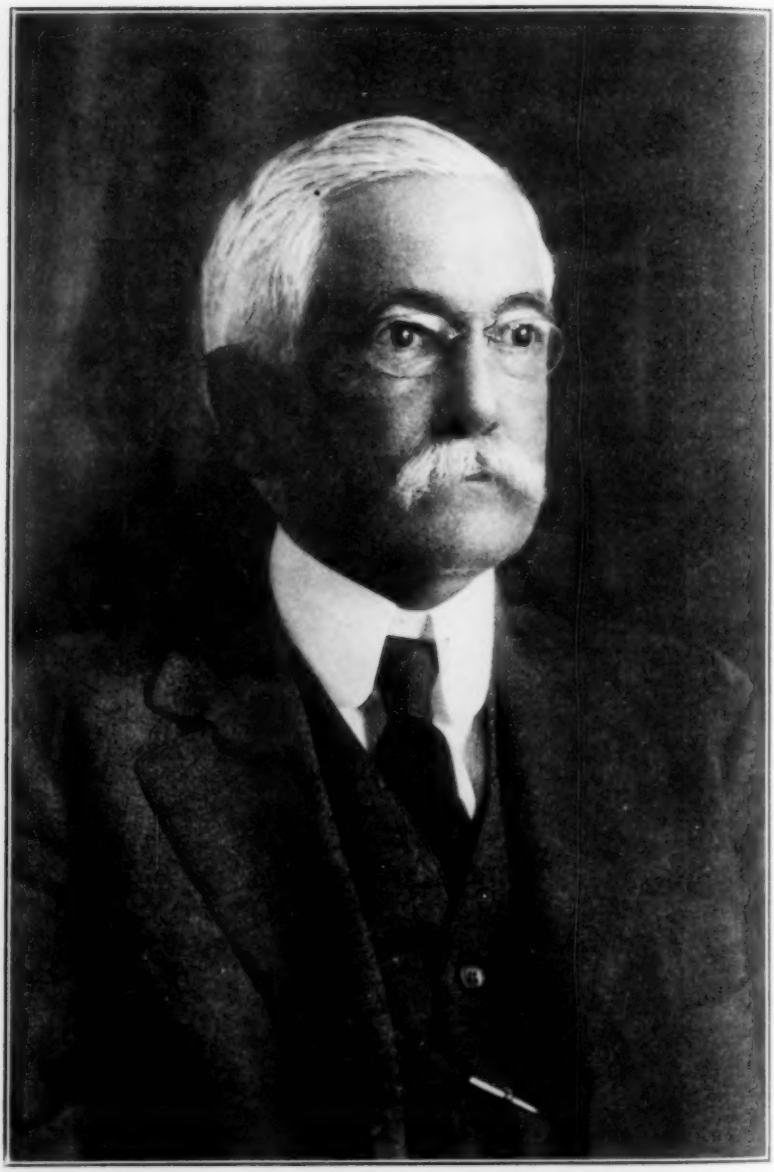
> Our present Hispanic-Peruvian civilization can be erected only on the aboriginal pedestal; and it can not stand firm and endure, if it does not completely adapt itself to the environment; if we do not seek to utilize our own resources, to discover the secrets and marvels of our nature, to admire the labor of our ancestors, to glorify the generations that have lived on our soil, wherein are preserved their ashes, and whence they drew their nourishment, and which they defended and used throughout many centuries. The present generation must revive the past and garner from it whatsoever can make it glorious.

Education can build a nation, but who will build the schools, furnish the texts or supply well-trained teachers? Surely the governments are not now in a position to do it. Who will break the in-

[4] Julio Tello, "Prehistoric Peru," *Inter-America* (April, 1922), pp. 238–250.

difference of the native and build up incentives? The church could if it were so minded. Who can take away the deadening coca which dulls the gnawing hunger and deadens the sensibilities to suffering, or the "chicha" and "aquardiente" which change, for the time being, a sordid world into a carefree one? Education can do it, yet the Indian may have to sing for a long time as in this verse translated from a Quechua poem:

> To shed a tear my heart was loath,
> Bitter as forgotten troth,
> None came to wipe my tear away
> To drink it was the only way.



ROBERT SIMPSON WOODWARD

President of the Carnegie Institution of Washington from 1905 to 1920 and previously, for twenty-two years, professor of mathematical physics at Columbia University, who died in Washington, on June 29, at the age of seventy-five years.

# THE PROGRESS OF SCIENCE

By Dr. EDWIN E. SLOSSON

SCIENCE SERVICE, WASHINGTON

## THE AMERICAN INVASION OF AUSTRALIA BY CACTUS

CACTUS is an American invention and a most ingenious contrivance for living in an arid land. Its thick stalks enable it, like the camel, to go long without water and their small surface prevents loss of water by evaporation. Its spines protect it from being eaten even where food is scarce.

Previous to the visit of C. Columbus to this country, the entire cactus family was exclusively American. Notwithstanding this fact, the cactus continues to be put into scenes of biblical life by painters, movie directors and writers. For instance, Donn Byrne plants cactus in a recent rewrite of the Gospel story.

But once America was opened to the world, the cactus spread and now is to be found in regions as remote as those reached by our sewing machines and phonographs and kerosene, but is not so popular. There being no patent on this American invention, local cactus plants have sprung up in various places that outstrip the original in production.

In Australia more than twice as much land is now occupied with the growing of prickly-pear than with all other crops put together. The latest estimate of the area infested or invested by the pest is put at 40,000,000 to 45,000,000 acres. This is larger than old England, larger than our Georgia. The invasion is still advancing and Queensland alone is losing usable land at the rate of over a million acres a year. And Australia can not afford to lose much land, for, although on the map its area is as great as that of the United States, so much of it is desert that it can never be expected to support more than a fifth of our population.

The prickly-pear was first carried to Australia in 1788 to serve as food for the cochineal insect, which had been brought from South America in the hope of starting a thriving industry in the dye stuff. The insect and the industry failed to thrive, but the prickly-pear did. It grew so well that certain squatters (a squatter in the Australian language is the same as a rancher in the American) took cuttings into the interior to plant cactus hedges around their stations (ranches). The hedges grew so well that in the course of time they covered all the land and the stations had to be abandoned.

The pest was introduced into Queensland by a country gentleman who on a trip to Sydney in 1858 was so much interested in this curious plant that he procured a joint and carried it carefully home in his saddlebag some four hundred miles. He planted it reverently in a choice spot of his garden and diligently tended it. Finally, the growth of two new branches proved that the transplantation was a success, and the proud owner was able to eat of its fruit. In fact the transplantation was more successful than any one had anticipated, and in 1921 the Queenslanders spent $390,000 trying to eradicate the prickly-pear, and yet they are losing ground.

The public land infected by the cactus can not be sold. It can not be given away. It can not even be given away with a bonus. The govern-

ment has offered a bonus as high as $20 an acre to any one who would take the land and clear it, but could not dispose of it at that. Land within twenty miles of a railroad has been offered free in lots of a thousand or two thousand acres on condition that it be freed from cactus within ten years, but there were no takers.

In America where the prickly-pear has been so long acclimated it is an interesting and comparatively innocent plant, though uncomfortable to those who come too close to it. It contributes a picturesque feature to an otherwise monotonous landscape and bears a delicious fruit for those who like it. But in the fresh fields and pastures new of Australia it flourishes better than on its native heath. The individual clumps measure ten to thirty yards in circumference and often stand so close as to be hog-tight. Surveying parties have to chop a path through it in places. When it is cut off the crop weighs 700 to 1,000 tons per acre. In New South Wales where four million acres are more or less infected the annual loss is estimated at $2,500,000.

How to get rid of the prickly-pear, or at least check its further spread, has been the subject of an investigation of a commission of the commonwealth under the scientific control of Dr. T. H. Johnston, of the University of Adelaide. His conclusion, as expressed to the Wellington meeting of the Australasian Association for the Advancement of Science, is that chemical means of extirpation, such as poisoning by arsenic, are so expensive as to be prohibitive, and that there is no probability that cactus can be turned into a source of income, as has been the case with another pest innocently introduced, the rabbit. He regards the prickly-pear as of little value as fodder for sheep or cattle. It has been found in New Mexico and South Africa that the juice of the fruit can be fermented and made into alcohol, but this, he concludes, could never be made profitable. There remains only the biological method of attack and Dr. Johnston proposes to draft into the warfare various sorts of bugs and worms, beetles and weevils, bacteria and fungi, that have been found preying upon the cactus in any part of the world. These, the natural enemies of the pestiferous plant, would attack it at all points, root, stem, segment and fruit, and by keeping up the conflict day and night may accomplish what man can not do directly.

It is an ingenious plan of campaign, but there is always the danger that the insect or parasite introduced to attack the cactus may find the crops as good or better feeding, and so the allies desert to the side of the foe. The lesson of it is that a nation can not be too careful what sort of immigrants it admits, be they vegetable, animal or human.

## FREE AIR

WIND was the first mechanical motive power that man learned to use. Probably it was discovered by some savage of a long gone age who made a sail of his blanket and a mast of himself, like Fayaway in Melville's "Typee," and so found his canoe propelled across the lake without the labor of rowing. From this simple craft was descended the skiff, the schooner and the full-rigged ship.

A few hundred years ago some one, perhaps a Dutchman, discovered that it was possible to attach the sails to a stationary post, instead of to a movable mast, and so make a windmill that would grind his corn. In England a windmill is mentioned as early as 1191. In France we can go back to a date of 1346, for we are told that Edward III viewed the battle of Cressy from a windmill.

But when the more convenient and reliable coal came in the local windmill and waterwheel went out, and the steamship replaced the sailboat. At the present time, little use is made of wind power, either on sea or land, although "free air" is to be had anywhere. But I venture to predict that sometime in the future— a wise prophet is indefinite as to date—the inexhaustible reservoir of kinetic energy in the moving atmosphere will be drawn upon for motive power to supplement or replace our stores of fossil fuel, now being rapidly exhausted.

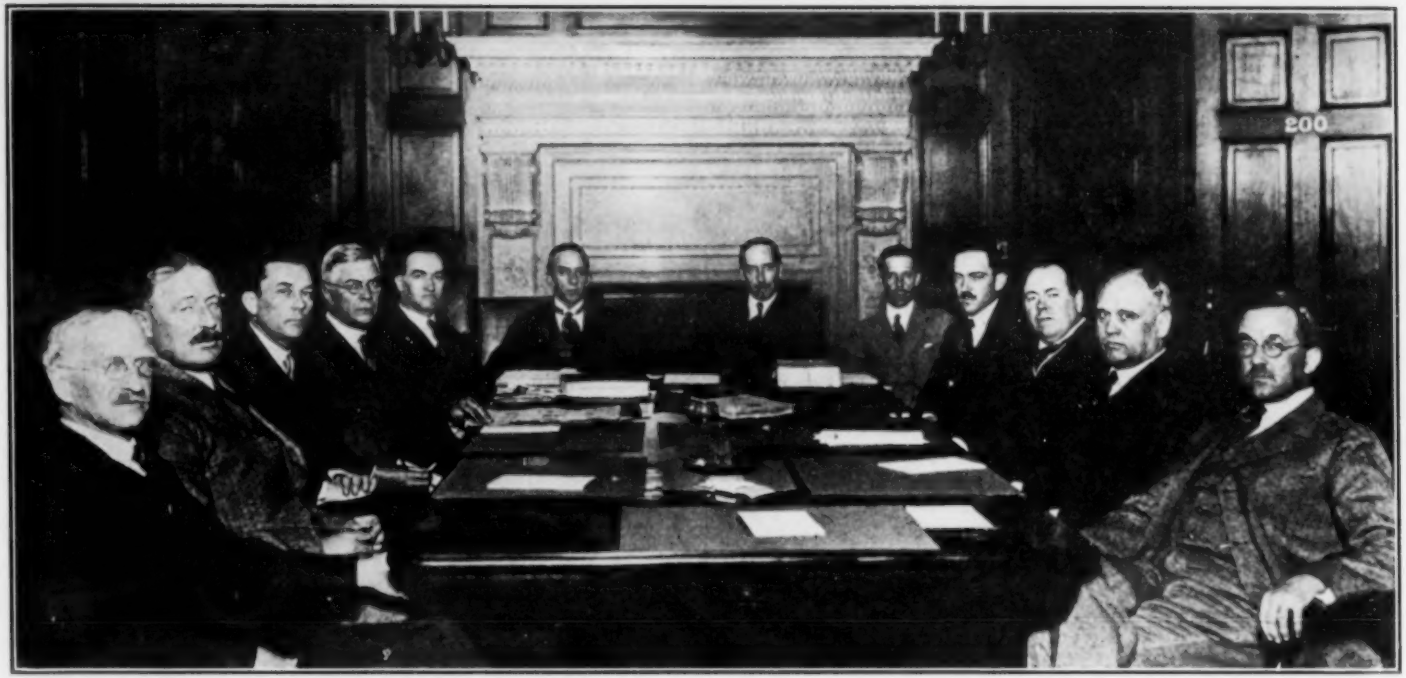
I imagine that sails will once again be seen upon the sea, more frequently than they ever have been before, and that landlubbers too will eventually find that they can not afford to neglect this freely flowing energy. It amounts to considerable if you figure it out. Suppose for instance that you live in one of those states where the velocity of the wind averages roughly 11 miles an hour throughout the year. This velocity of air represents about one tenth of a horse power per square meter at right angles to the wind. A layer of this wind, 66 feet deep and 425 miles from side to side, would represent 1,368,000 horse power.

I do not wish, however, to be understood as saying that a farmer could put up a row of windmills and extract all the energy from the passing breeze. This would, of course, mean stopping the wind entirely, and would result in an uncomfortable accumulation of dead air on the farm that would be difficult to dispose of. And his neighbor next beyond would not be able to raise the wind.

But it does seem to me that we might well utilize even now a little more than we do of this vagrant wealth. It is purely a practical problem of collecting and storing and delivering scattered and variable quantities of energy, the same problem as we shall have to solve if we are to utilize the wasted power of our minor streams and fluctuating tides.

At present the most practical way of storing wind power is by employing it to pump up water into a tank so as to use the gravitational force of its fall when wanted. But this method is of limited application. A more promising scheme is to use the surplus wind power in charging a storage battery from which electrical currents can be drawn as needed. But on account of the expense and difficulty of keeping up an extensive storage battery system this has not yet come into common use, although there are several practical wind-electric outfits now being manufactured in this country. Another and more ambitious plan of solving the problem is proposed by J. B. S. Haldane, of Cambridge, who has the most far-reaching imagination of any biologist since Wells grew up. In his new book, "Daedalus" he foresees the time when England will be covered with rows of metallic windmills running dynamos. The surplus power of these will be used for decomposing water into hydrogen and oxygen, which will be liquefied and stored underground in great jacketed reservoirs. In times of calm the two gases will be again combined and since they produce the most heat of any chemical reaction, they would be used in gas engines. But even Mr. Haldane puts this four hundred years in the future.

The modern wind motor is more efficient than the steam engine as an energy transformer since it can utilize some 15 per cent. of the power of the wind that reaches it, while an ordinary steam engine does not ordinarily utilize more than 13 per cent. of the energy of the coal. But the water turbine is far more economical than either, since it can make available 70 per cent. or more of the energy it receives. In experiments made some years ago at the Agricultural Experiment Station of North Dakota,




ARCHEOLOGICAL CONFERENCE AT THE CARNEGIE INSTITUTION OF WASHINGTON

Conference of leading archeologists and anthropologists of the United States, with Dr. Manuel Gamio, director of the Bureau of Anthropology of Mexico, which considered the explorations of the Carnegie Institution in Yucatan. From left to right are: Professor Byron Cummings, University of Arizona; Professor A. V. Kidder, Phillips Academy, Andover, Mass.; Clarence L. Hay, American Museum of Natural History; Dr. H. J. Spinden, Harvard University; Neil M. Judd, U. S. National Museum; Dr. Manuel Gamio; Professor Eugene M. Gomez Maillefert, Bureau of Anthropology of Mexico; Dr. J. C. Merriam, President of the Carnegie Institution; Dr. S. G. Morley, Carnegie Institution; Earl H. Morris, Carnegie Institution; Dr. Mitchel Carroll, George Washington University; Professor A. M. Tozzer, Harvard University; Professor R. V. D. Magoffin, president of the Archeological Institute of America.

it was found that the cost of electricity from a windmill in that state was only about a third of its cost from a gasoline engine, and that the initial expense of the two outfits was practically equal. The Agricultural Experiment Station of Wisconsin found that the wind in that state could be depended upon to blow at the rate of nine miles an hour or more for five thousand hours in the year. This is sufficient to run a windmill, which therefore would be working 14.3 hours a day on the average. A 16-foot geared windmill would furnish two horse-power for ten hours a day. The Germans are experimenting on gigantic wind power plants to replace the coal they lost through the war, and it is claimed that these can produce current at a cost of less than a cent per kilo-watt-hour.

It is to be hoped that some day we may be able to get our power from the clean and open air rather than from the dark and dirty mine. A row of revolving vanes on a hilltop is certainly more picturesque than an oil derrick or coal dump. There would also be gain from a sociological as well as from an esthetic standpoint, since wind power is to be had almost everywhere and can not be monopolized like coal and oil. It is a decentralized source of power, and it is inexhaustible.

**CONTAGIOUS HEALTH**

When Bob Ingersoll was lecturing on "The Mistakes of Moses," he was asked sarcastically if he thought he could do any better if he were running the universe. He replied "Yes," and when challenged to specify in what particular he could improve on the present administration he answered that if he were the Almighty he would make health contagious instead of disease.

This, like other of his witty retorts, will not stand close scrutiny. In fact, recent researches indicate that the proposed improvement is already in existence and has been for ages. As we now know the microbes are not all enemies of man. Some are his active allies, and they carry on warfare in his defense in much the same way as the disease-producing kinds do against him.

A French biologist, d'Herelle, discovered in 1917 that bacteria are preyed upon by something yet smaller than themselves; something too small to be seen with any microscope or to be filtered out from a fluid, for they will pass even through the pores of porcelain. "Bacteriophages," he calls them—"bacteria-eaters." They are so minute that it would seem that they must belong to the field of chemistry rather than biology, yet they grow and propagate and maintain a definite individuality like living creatures. They are normally present in our digestive tube and protect us by breaking down and dissolving inimical bacteria. The greater the number of the invading hosts, the faster the bacteriophages multiply and the fiercer they become in fight, until finally they have overcome the infection. They may then in the flush of their victory carry their campaign into the enemy's country and cure others of the community. The sick persons who have been cured thus become carriers of the cure and centers of healing infection, so starting an epidemic of health. As d'Herelle says in his new book "Defenses of the Organism":

> A sick animal propagates the disease. . An animal in a state of active resistance propagates immunity. These few words sum up the whole history of epidemics.

Dr. d'Herelle may be over-sanguine in thinking that he has seized the whole secret of epidemics, but his discoveries are in line with the modern

*Wide World Photos*

**"PALE FACE" INDIANS FROM PANAMA**

**Three "White Indian" children brought to New York by Richard O. Marsh from the little known San Blas Country of Panama, photographed at their New York hotel. The two boys and a girl, ranging in age from ten to sixteen, have golden white hair and eyebrows, hazel eyes and pink skin. Their parents are said to be copper colored. There are said to be hundreds of blond Indians in the region.**

methods of medical practice, which is to enlist the aid of bacteria in our defense against bacteria and to promote civil war in the Kingdom of the Protozoa. We have already in our midst an army of defenders in the form of white corpuscles of the blood, and these may be multiplied and encouraged to greater exertions by medical means. We may counteract a toxin with an antitoxin. We may, as Metchnikoff advised, colonize the colon with the benign bacteria that produce lactic acid, in place of those that produce poisons. We may infest parasites with minor parasites. We may set the ultramicrobe to catch the microbe.

In this way we may hope to stave off the day when we shall fall victim to the innumerable hosts of invisible foes that continually beset us, though, so far, they have in the end come out conquerors in every case. "A bacillus less than one five thousandths of an inch in length, multiplies, under normal conditions, at a rate that would cause the offspring of a single individual to fill the ocean to the depth of a mile in five days." The cholera bacillus doubles in numbers every twenty minutes. How can a clumsy creature like man, who requires twenty years to grow up, ever hope to compete with such a rapid multiplier? Yet somehow he does manage to overcome the cholera and keep it under control. He even begins to believe that he may in the course of time completely exterminate those disease germs which must live on and in man, for once every patient were cured or secluded these would vanish from the earth, never to reappear. So man by the aid of science may in time vanquish the earth-born myrmidons of his arch enemy, Beelzebub, God of Flies and Vermin.

**EDUCATION ESCAPING FROM THE SCHOOLROOM**

Once upon a time a country school teacher rang her bell after recess but none of the children came in. She went outdoors to see what was the matter and found them all gathered along the roadside. "Oh, teacher," cried the children, "Can't we stay out a minute longer? There is a circus coming by and we want to see the elephant." The teacher hesitated a moment but she was a conscientious woman and knew her duty. "No, children," she said, "Work must come before play." So she gathered them all in and shut the door and set them at their reading lesson, which was on "The elephant, its appearance and habits."

Now like all fables this is capable of being interpreted in various ways. It may be argued that moral training is of greater value than informational acquirement, that it was more important that the children should acquire the habit of obedience and be able to resist the temptation to distraction of attention by passing events than that they should learn how an elephant looked. Put to the pragmatic test who of us can say that his conduct or happiness in life has been materially affected by his knowledge that the elephant is distinguished by the possession of two tusks and a trunk?

But if we consider the question from a purely pedagogical point of view and assume that the teacher's duty was that prescribed by the curriculum, namely, the imparting of information about the elephant, then we must admit that she did not adopt the best plan for the purpose, that she adhered too closely to methodology, that she failed to recognize that there are different ways of getting at the same thing, in short, that she allowed the means to obscure the end, which is a common fault of ordinary people as well as of school teachers.

Science has produced so many new ideas in recent years that they have burst through the walls of schoolroom and laboratory and have escaped into the open. No professor can now maintain a monopoly of his own profession. He will often meet with men who know as much as he does about his science and yet have no title in front of their names nor degrees trailing after them. Day by day in every way it is getting harder and harder for the teacher to keep ahead of his students. More and more the students are learning science out of school. I fancy it would have taken many years for the new theories of electricity to have been incorporated into the common mind if the radio had not come along to help out the teacher. But now we have kids talking about electron streams and metric wave lengths as they skate along the streets. And they know what they are talking about as they can demonstrate by making radio receivers that work.

I fancy more physics has been taught to the present generation by the automobile than by the professors. The automobile is autocratic in its methods. It has the habit of stopping suddenly in the middle of the highway or on a railroad crossing and giving the chauffeur a quiz on the chemistry of combustion or the laws of mechanics. And the chauffeur is not allowed to pass until he has given a practical demonstration of his knowledge. Seventy per cent. of book learning will not suffice.

This spread of science to the outside world is scary to the teacher who is secretly unsure of his own knowledge and therefore prefers to cling closely to his text-book. But the competent and confident teacher will welcome the new opportunities it offers for extending his influence outside his class room and awakening more interest within.